Investigation of Spatial and Temporal Variation of Air Toxics in The Seattle Area

Prepared for John Williamson
Air Quality Program
Washington Department of Ecology

By

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Outline

- Introduction
- Study design
- Data issue (metals)
- Temporal and Spatial Variations
  - ANOVA and General linear model for individual toxics
  - Principle component analysis for congregate toxics
- Risk Analysis
- Conclusions
- Limitations

Introduction

- NATA 1996
  - Ambient concentrations: ASPEN model and 1996 emission inventory data
  - Inhalation exposure: HAPEM4 model and results from ASPEN model
  - Risk assessment in US for 33 HAPs
- Issues
  - Performance of models
  - Unknown uncertainties associated w/ model predictions and risk estimates
  - Temporal variability in modeled data
- Six pilot cities for air toxics measurements

Objectives

- Characterize ambient air toxics concentrations
- Evaluate spatial and temporal variability of ambient air toxics

Study Design

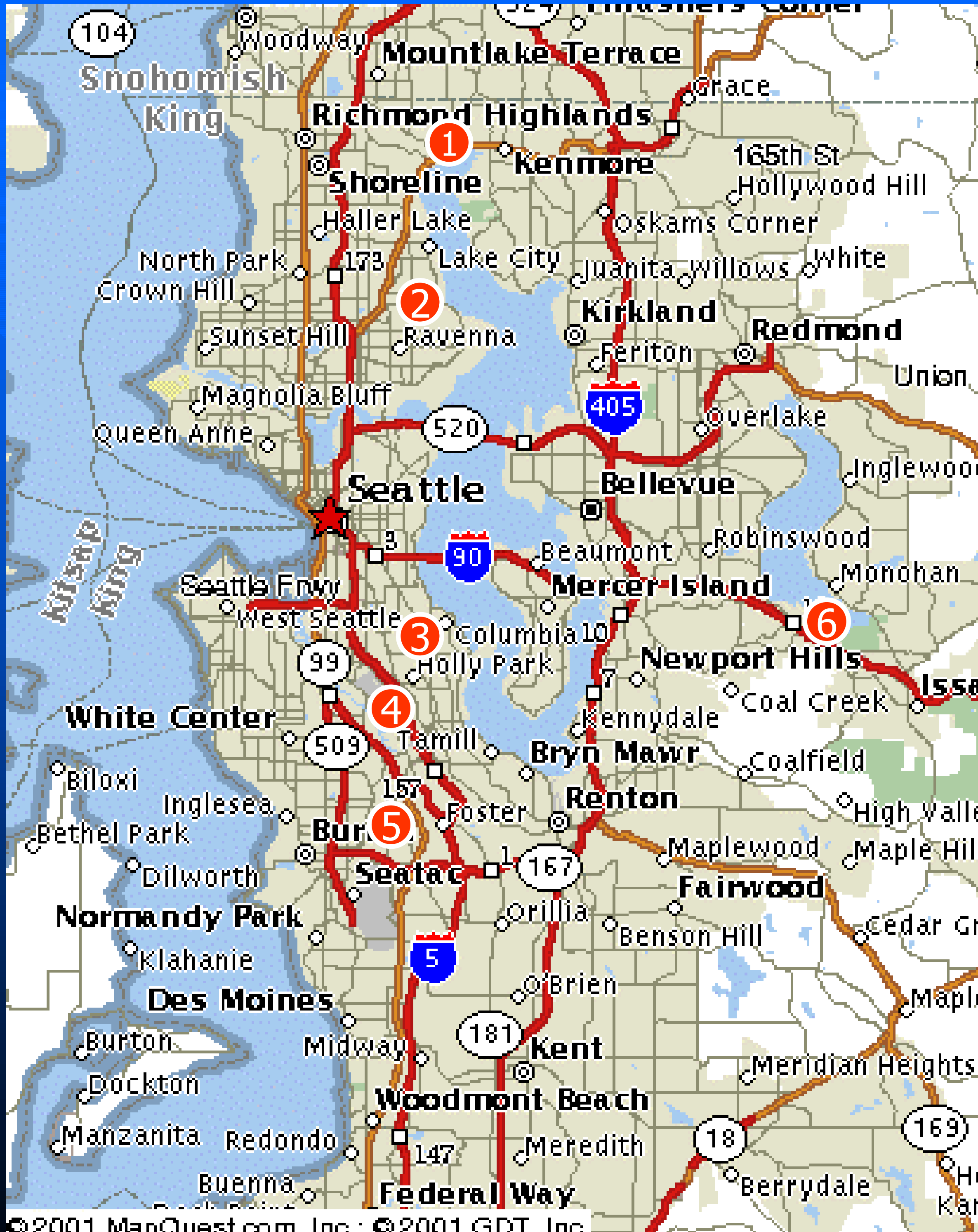
- Neighborhood to urban scale
- Located in distinctly different sub-regions within the urban area to evaluate spatial variability
- Sited to assess mobile, industrial, wood smoke & area sources
- Sampled for VOCs, Carbonyls & speciated PM
- 24 hour integrated samples every 6^{th} day

Study Design – Contd.

Year 2000		
HAP	sampling site	period
VOCs	BH, GT	Jan-Dec
Metals (PM2.5)	BH, GT	BH: Feb-Dec GT: May-Dec

Year 2001		
HAP	sampling site	period
VOCs	BH, GT, LF, LS, ML, ST	BH, GT: Jan- Others: Feb-
metal (PM2.5)	BH, GT	Jan-
metal (TSP)	LF, LS, ML, ST	Feb-

Mar 2001 ~ Feb 2002: 6 sites, all metals and VOCs for 1 year



1 Lake Forest Park

2 Maple Leaf

3 Beacon Hill

4 Georgetown

5 SeaTac

6 Lake Sammamish

Measured Hazardous Air Pollutants (HAPs)

- VOCs
  - Benzene
  - 1,3-butadiene
  - Carbon tetrachloride
  - Chloroform
  - Dichloromethane
  - 1,2-dichloropropane
  - Tetrachloroethylene
  - Trichloroethylene
  - Vinyl chloride
- Carbonyls
  - Acetaldehyde
  - Formaldehyde
- Metals
  - Arsenic
  - Beryllium
  - Cadmium
  - Chromium
  - Lead
  - Manganese
  - Nickel

Analytical methods

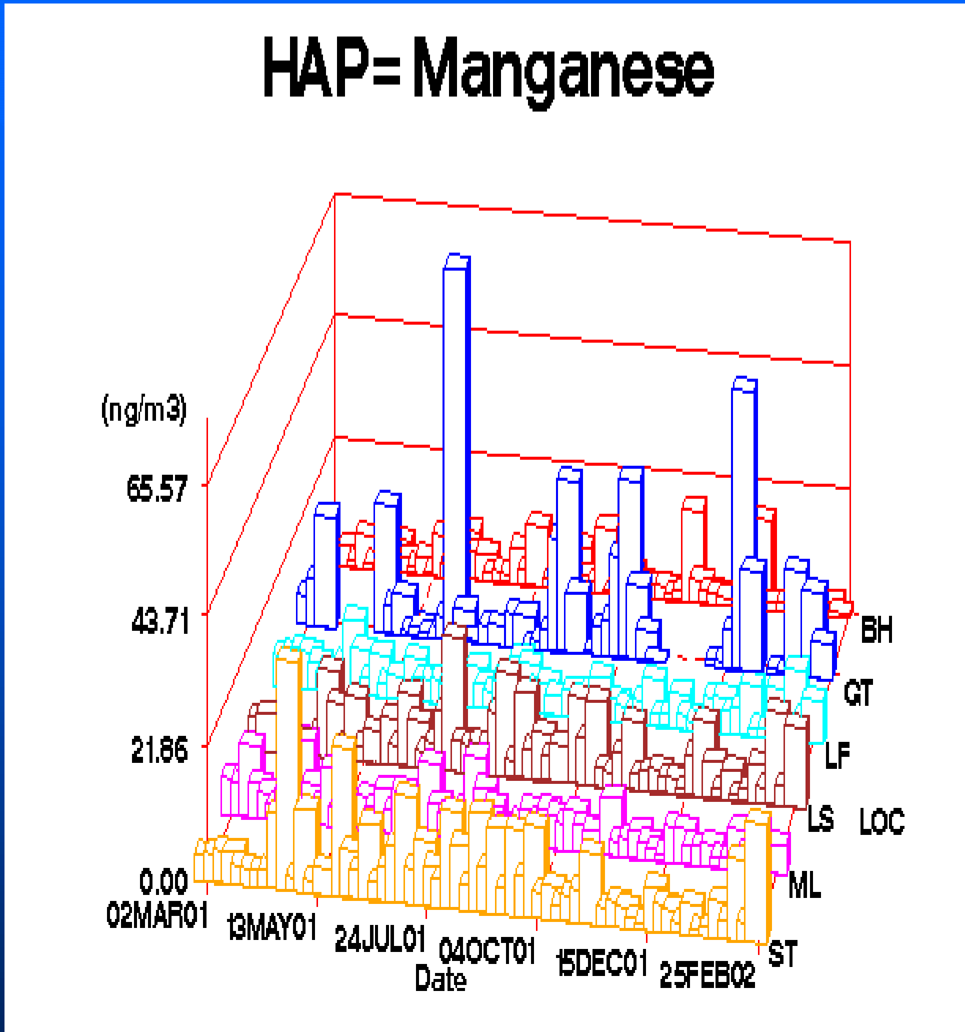
HAP	Sampling method	Analytical method	Sites
Carbonyls	Sep-Pak cartridge	HPLC-UV	All sites
VOCs	Canister	GC FID/ECD	All sites
Metals ($PM_{2.5}$)	Teflon filter	XRF	BH, GT
Metals (TSP)	Quartz filter	ICP-MS	LF, LS, ML, ST

Summary of data

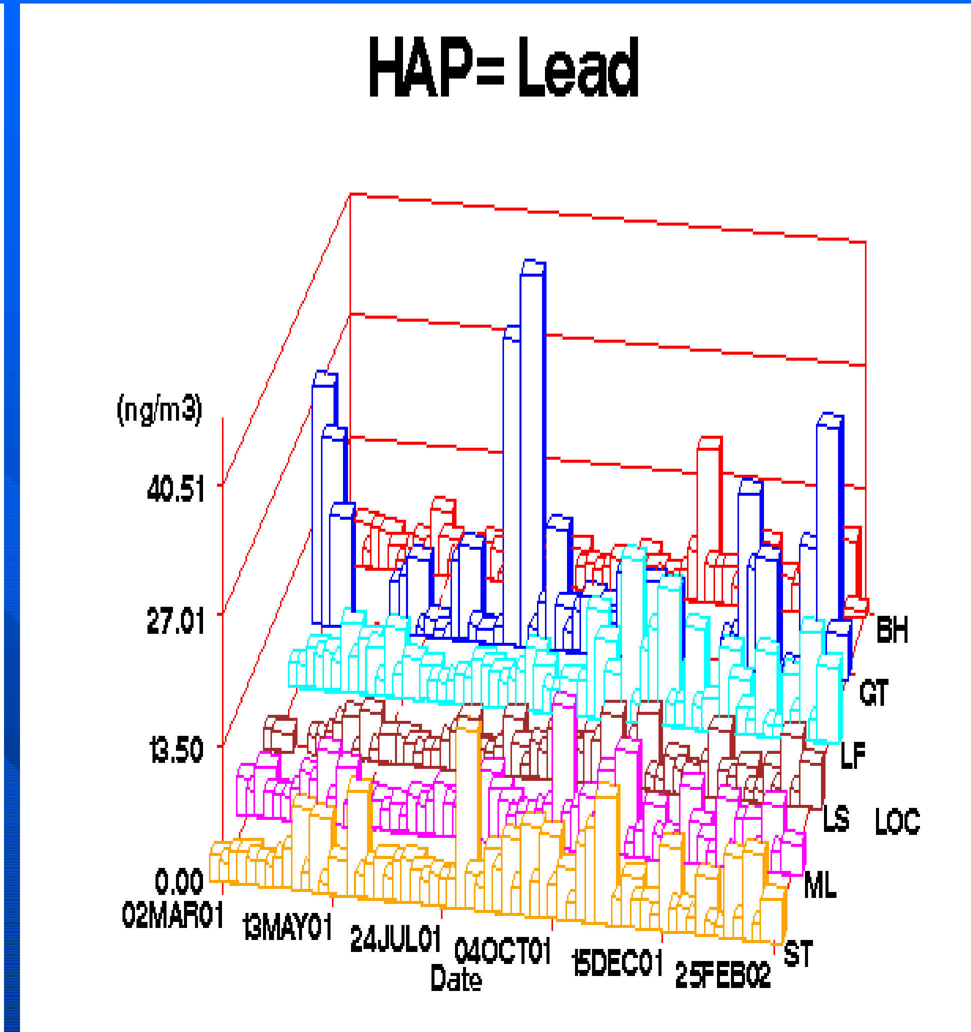
Concentration of Metals (summary statistics across 6 sites)

Analysis Variable : conc (ng/m^3)								
Name of HAP	**N**	**Mean**	**Median**	**Std Dev**	**5th Ptcl**	**25th Pctl**	**75th Pctl**	**95th Pctl**
Manganese	326	6.373	4.673	6.600	1.060	2.825	7.250	16.575
Lead	327	4.726	3.486	4.430	1.283	2.460	5.370	11.655
Nickel	324	1.773	1.168	2.886	0.280	0.678	1.945	4.665
Chromium	324	1.448	0.953	1.780	0.240	0.569	1.652	4.335
Arsenic	328	1.061	0.729	1.002	0.100	0.427	1.409	2.920
Cadmium	327	0.309	0.100	0.603	0.030	0.050	0.199	1.673
Beryllium	234	0.003	0.001	0.004	0.000	0.000	0.004	0.011

Concentration of Metals

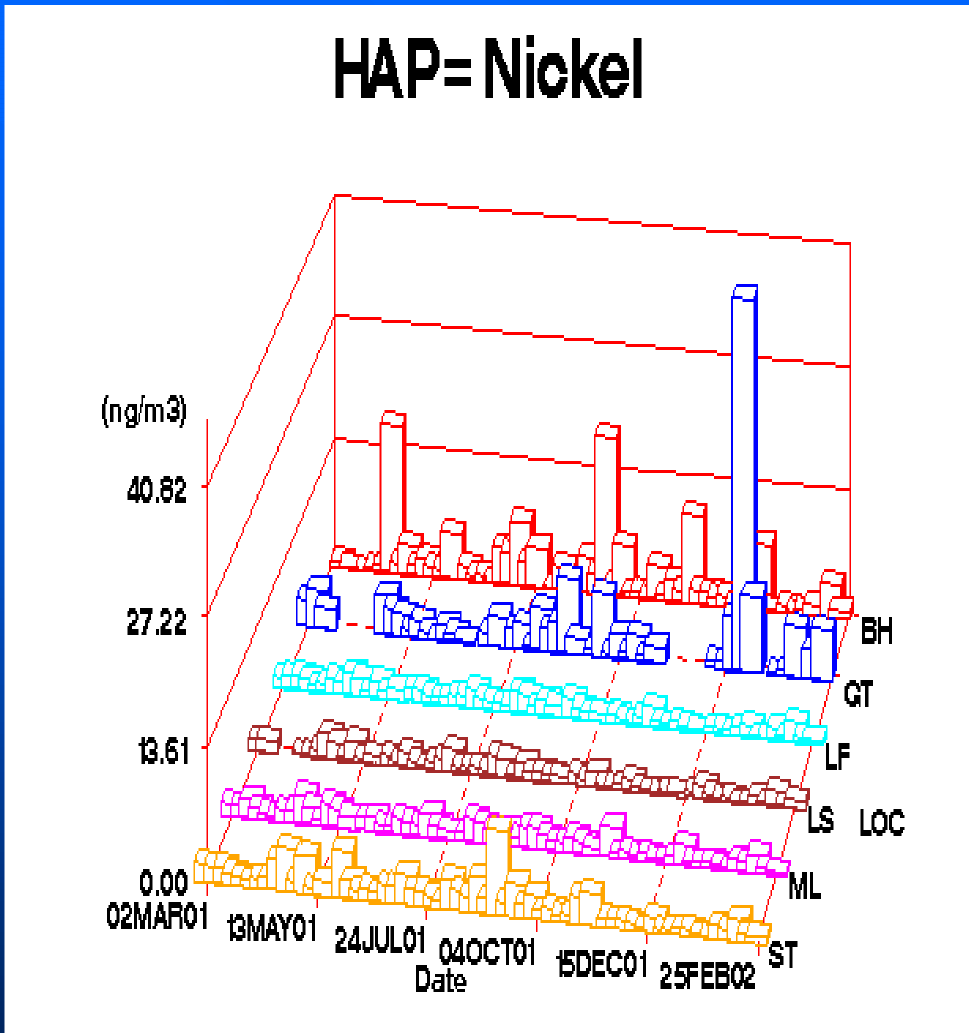


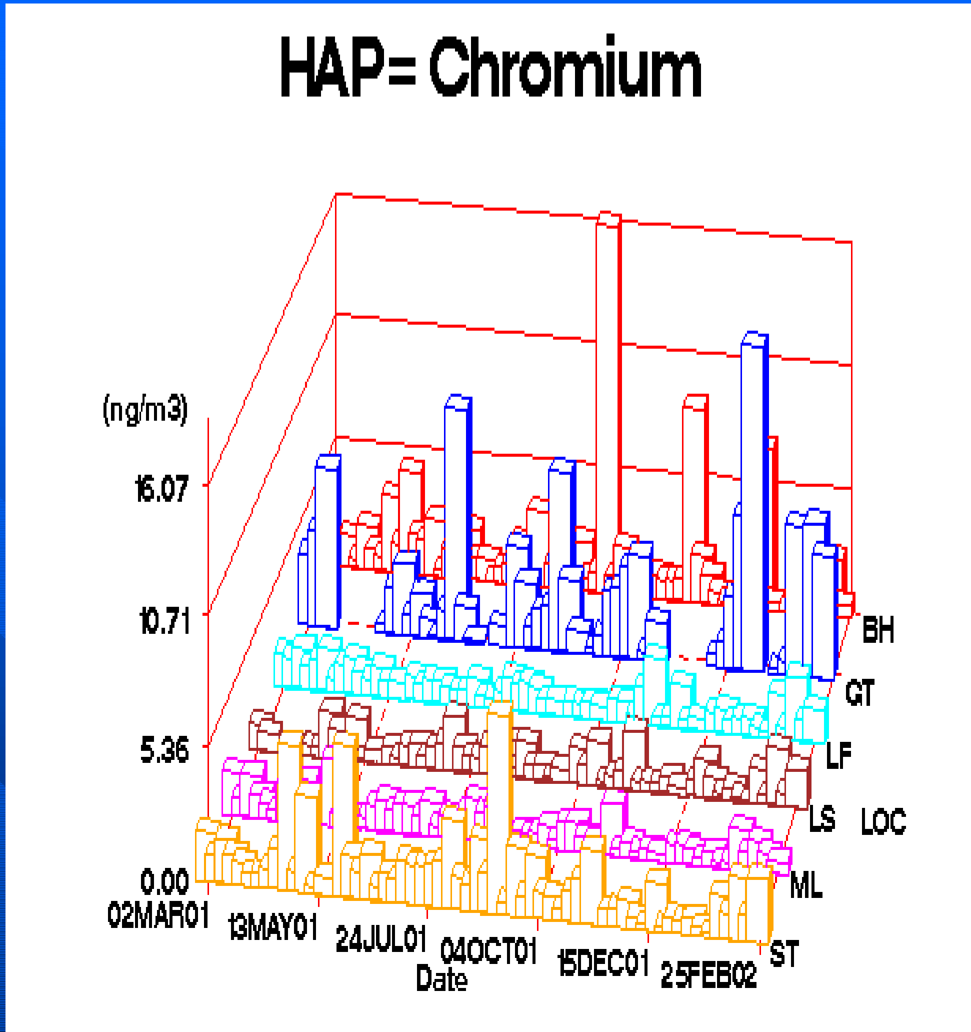
Analysis Variable : conc (ng/m3)								
loc	N	Mean	Median	Std Dev	5th Ptcl	25th Pctl	75th Pctl	95th Pctl
BH	54	3.554	2.432	3.563	0.471	1.413	4.192	11.598
GT	42	10.222	5.548	13.520	0.470	1.317	14.970	31.383
LF	57	5.126	4.309	2.513	1.560	3.500	6.604	9.552
LS	56	6.942	5.361	4.866	1.910	2.966	9.808	15.850
ML	58	5.535	4.825	2.842	1.780	3.500	6.389	12.460
ST	59	7.700	5.150	6.655	1.600	3.315	10.834	19.680



Analysis Variable : conc (ng/m3)								
loc	N	Mean	Median	Std Dev	5th Ptcl	25th Pctl	75th Pctl	95th Pctl
BH	55	3.535	3.109	2.359	0.988	2.400	4.142	7.109
GT	42	8.598	5.583	9.177	0.730	2.119	11.017	27.160
LF	57	5.051	3.852	3.418	1.590	2.677	6.688	11.655
LS	56	3.269	2.919	1.813	1.220	1.955	4.015	7.450
ML	58	4.258	3.576	2.416	1.580	2.739	5.236	8.700
ST	59	4.609	3.416	3.294	1.380	2.520	5.950	10.910

Concentration of Metals

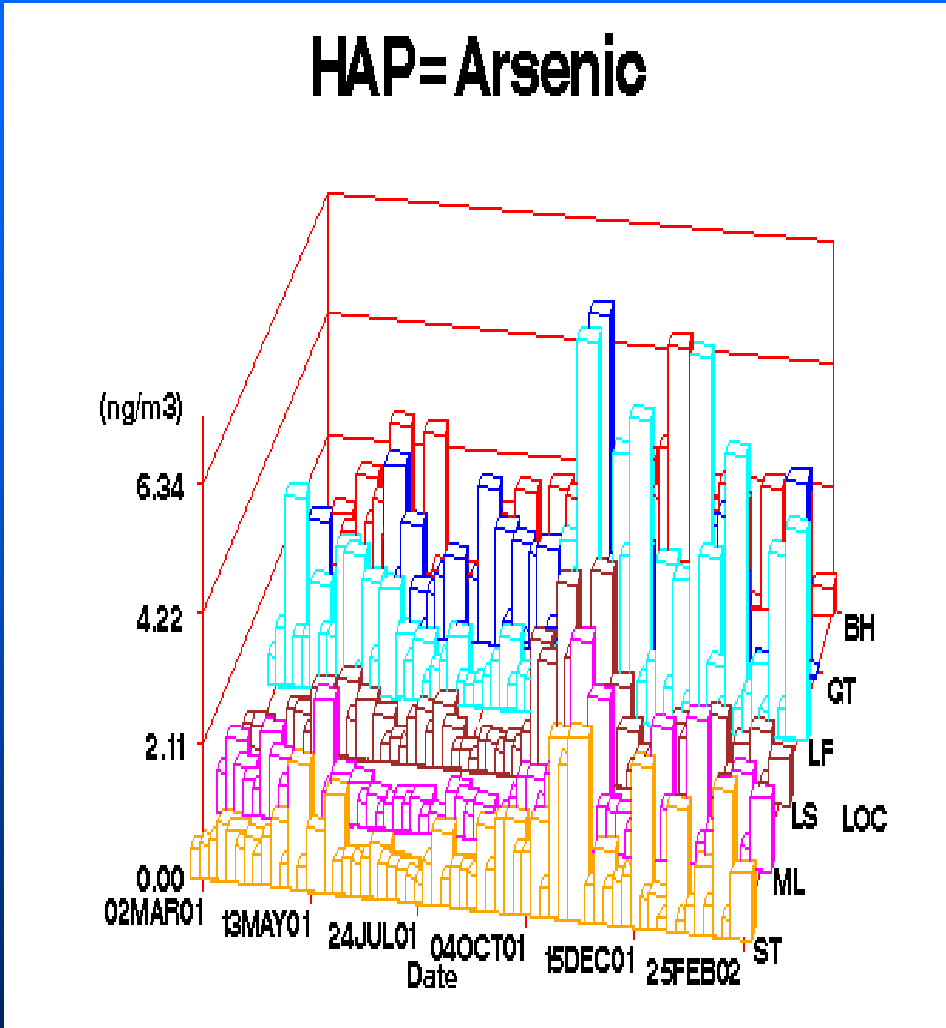


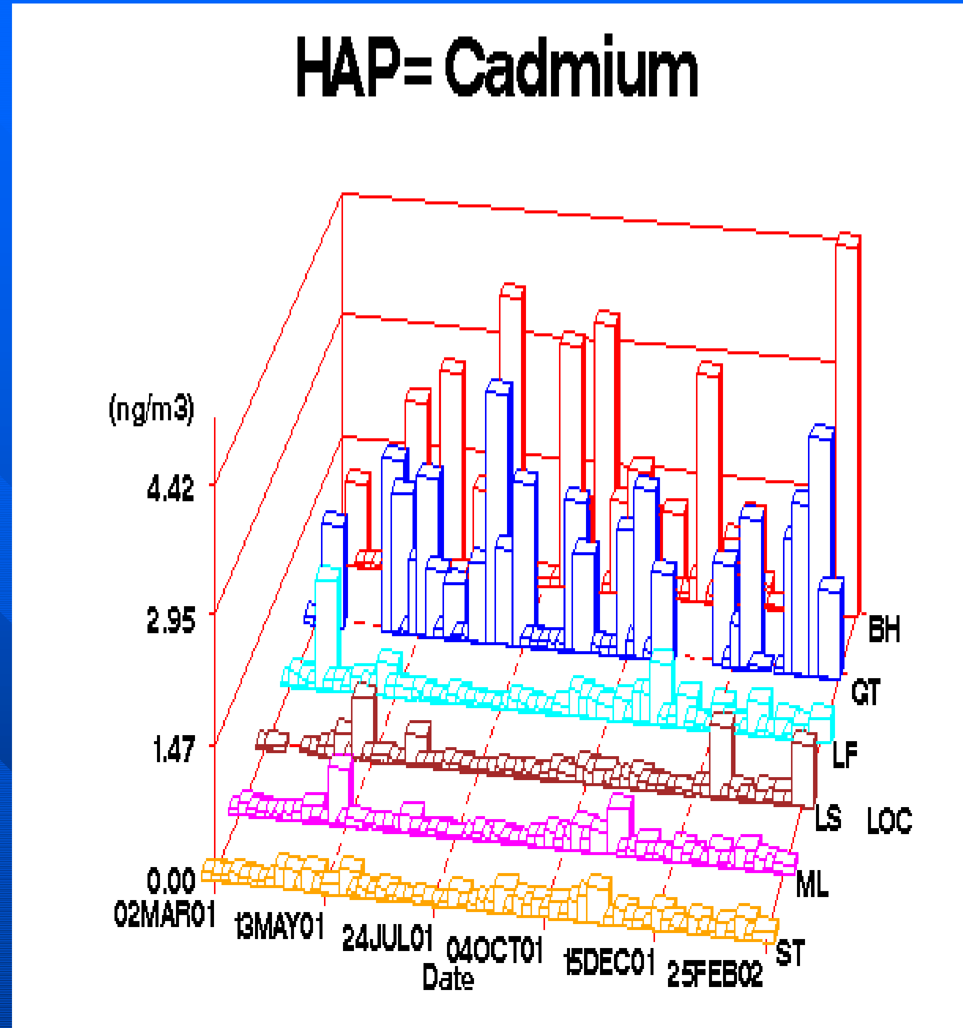


Analysis Variable : conc (ng/m3)								
loc	N	Mean	Median	Std Dev	5th Pctl	25th Pctl	75th Pctl	95th Pctl
BH	54	2.495	1.175	3.517	0.187	0.658	3.200	9.792
GT	41	3.565	2.214	6.339	0.329	0.896	3.300	8.322
LF	57	1.118	0.961	0.578	0.220	0.670	1.436	2.140
LS	55	0.901	0.715	0.642	0.200	0.380	1.286	2.294
ML	58	1.300	1.260	0.700	0.410	0.749	1.760	2.514
ST	59	1.775	1.358	1.438	0.350	0.910	2.095	4.597

Analysis Variable : conc (ng/m3)								
loc	N	Mean	Median	Std Dev	5th Pctl	25th Pctl	75th Pctl	95th Pctl
BH	55	1.687	0.962	2.497	0.050	0.613	1.900	7.010
GT	41	2.997	1.930	2.984	0.250	0.896	4.100	7.760
LF	57	0.990	0.850	0.537	0.390	0.631	1.246	1.900
LS	55	0.883	0.704	0.602	0.180	0.426	1.235	2.311
ML	57	0.908	0.767	0.541	0.290	0.522	1.248	1.800
ST	59	1.637	1.138	1.487	0.250	0.710	1.860	6.030

Concentration of Metals

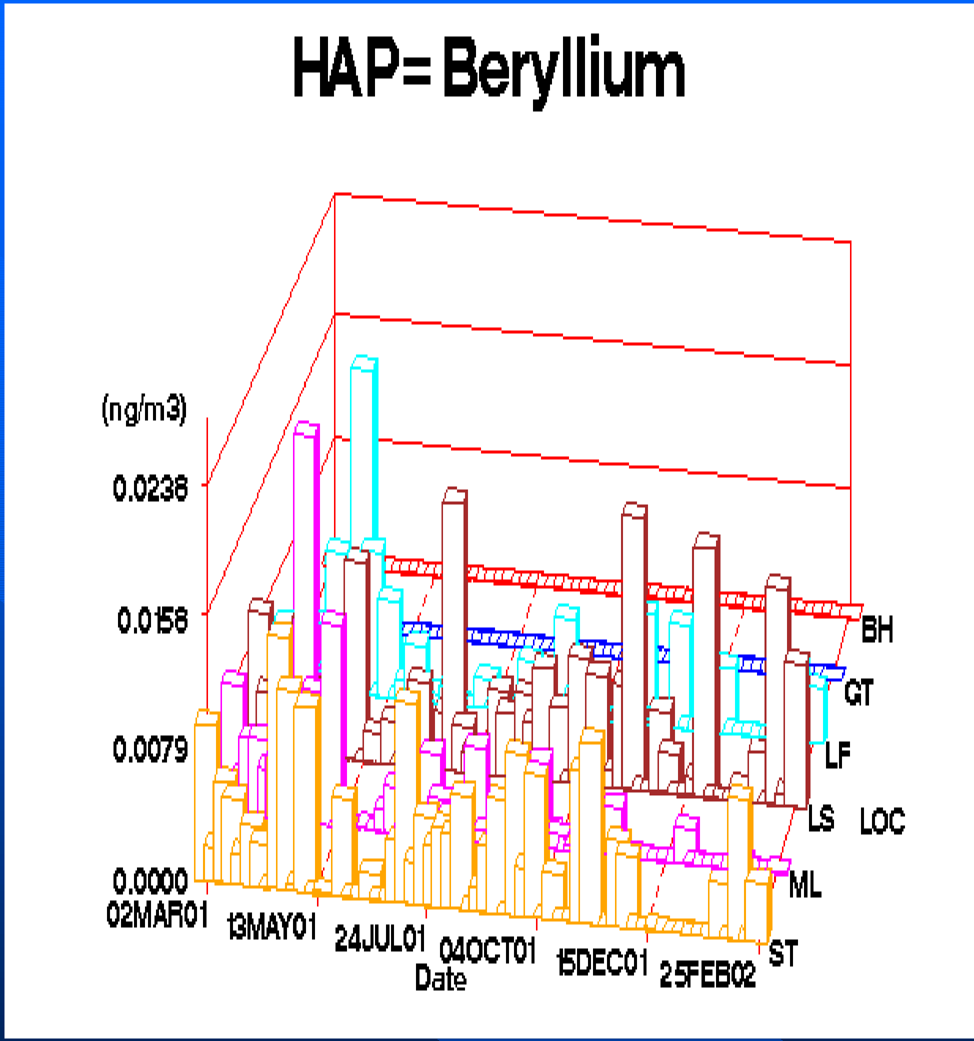




Analysis Variable : conc (ng/m3)								
loc	N	Mean	Median	Std Dev	5th Ptcl	25th Pctl	75th Pctl	95th Pctl
BH	55	0.910	0.600	0.925	0.050	0.100	1.600	2.542
GT	42	1.267	1.214	1.171	0.090	0.160	1.838	2.873
LF	58	1.593	0.955	1.480	0.369	0.570	2.332	5.110
LS	56	0.860	0.677	0.704	0.213	0.398	1.055	2.290
ML	58	0.834	0.606	0.625	0.281	0.450	1.003	2.390
ST	59	0.947	0.663	0.667	0.310	0.511	1.110	2.590

Analysis Variable : conc (ng/m3)								
loc	N	Mean	Median	Std Dev	5th Ptcl	25th Pctl	75th Pctl	95th Pctl
BH	55	0.639	0.100	1.027	0.050	0.050	0.988	3.225
GT	42	0.866	0.729	0.855	0.050	0.100	1.600	2.072
LF	58	0.163	0.108	0.200	0.027	0.047	0.197	0.402
LS	55	0.121	0.070	0.169	0.018	0.041	0.131	0.715
ML	58	0.108	0.064	0.113	0.027	0.048	0.133	0.299
ST	59	0.123	0.092	0.082	0.039	0.059	0.189	0.288

Concentration of Metals

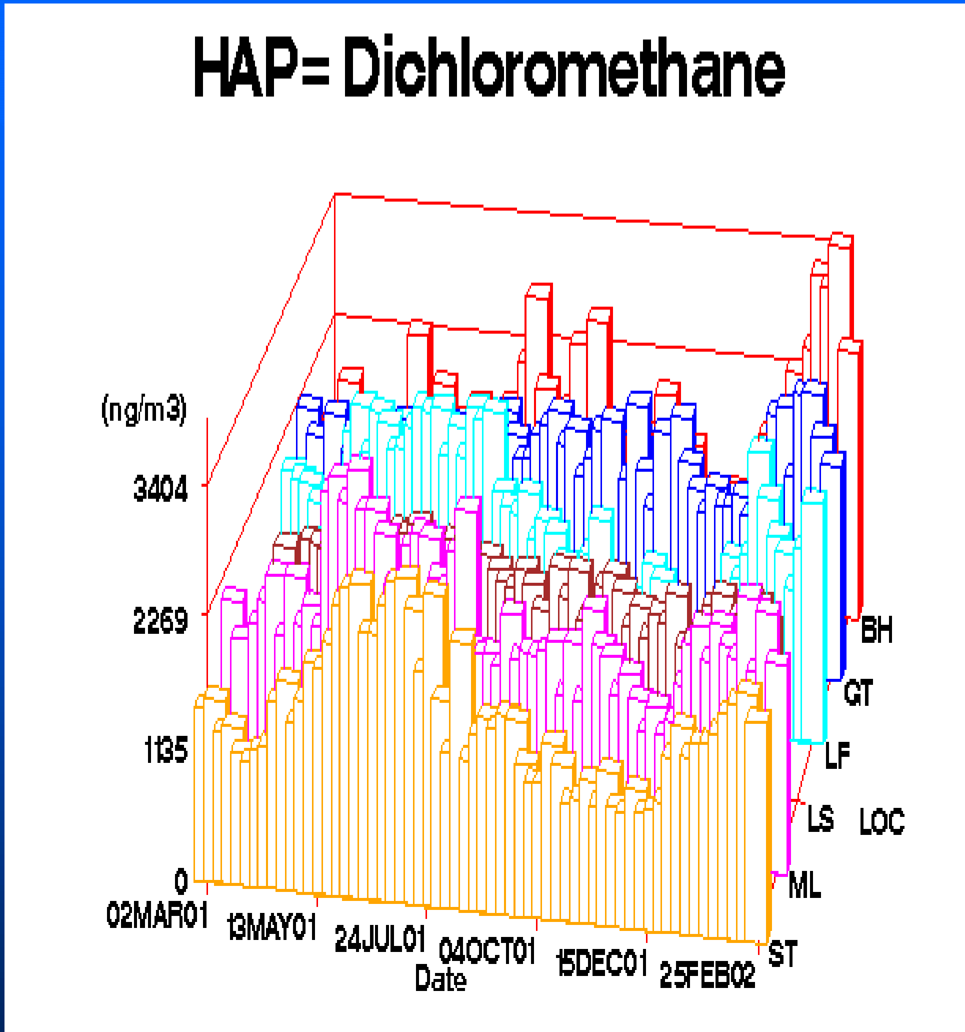


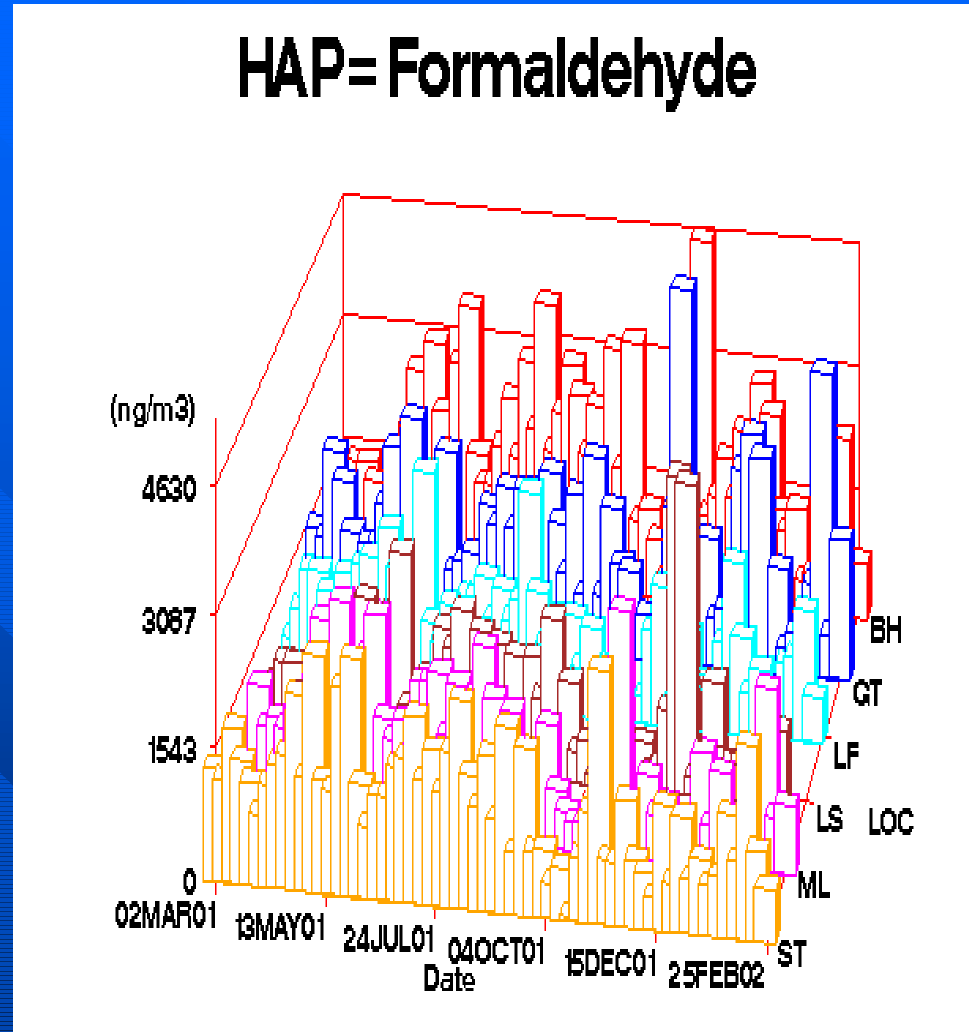
Analysis Variable : conc (ng/m3)								
loc	N	Mean	Median	Std Dev	5th Pctl	25th Pctl	75th Pctl	95th Pctl
BH	0	.	.	.	.	.	.	.
GT	0	.	.	.	.	.	.	.
LF	59	0.002	0.000	0.003	0.000	0.000	0.003	0.009
LS	57	0.004	0.002	0.005	0.000	0.000	0.005	0.015
ML	59	0.002	0.000	0.004	0.000	0.000	0.002	0.008
ST	59	0.003	0.003	0.004	0.000	0.000	0.005	0.012

Concentration of VOCs (summary statistics across 6 sites)

Analysis Variable : conc (ng/m^3)								
Name of HAP	**N**	**Mean**	**Median**	**Std Dev**	**5th Ptcl**	**25th Pctl**	**75th Pctl**	**95th Pctl**
Dichloromethane	352	1753.0	1733.2	507.8	985.2	1411.9	2015.6	2681.0
Formaldehyde	348	1315.1	1228.2	772.3	307.1	736.9	1719.5	2824.9
Acetaldehyde	351	1250.7	1081.2	683.4	540.6	901.0	1441.6	2342.7
Benzene	354	1239.7	1081.5	764.1	464.9	707.0	1520.7	2675.7
Carbon_Tetrachloride	351	622.5	630.8	93.1	472.5	562.0	673.1	766.2
Tetrachloroethylene	351	207.7	133.4	240.7	33.9	74.6	236.0	664.7
Trichloroethylene	350	205.7	156.2	233.6	43.0	89.0	235.5	543.2
Chloroform	351	157.2	113.6	116.5	53.7	77.2	214.8	356.4
Butadiene	354	95.1	66.4	107.1	22.1	42.0	108.4	280.6

Concentration of VOCs

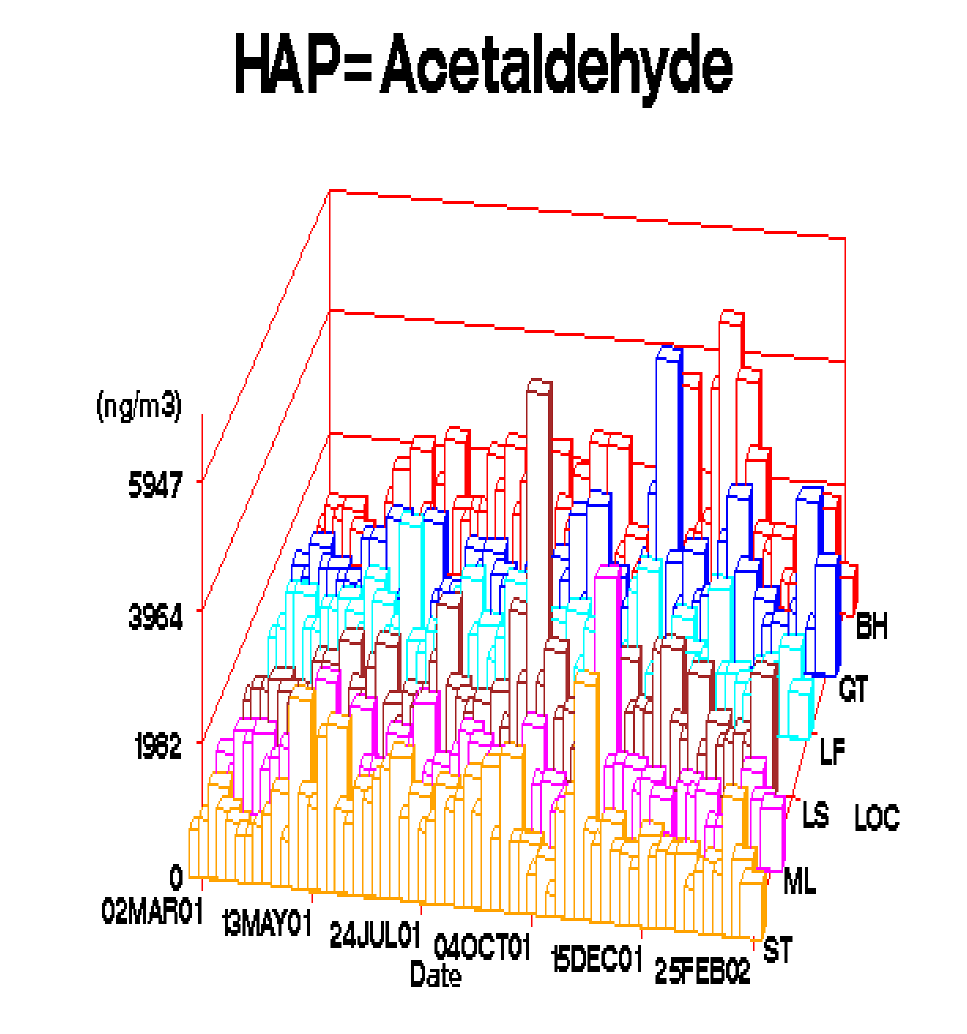


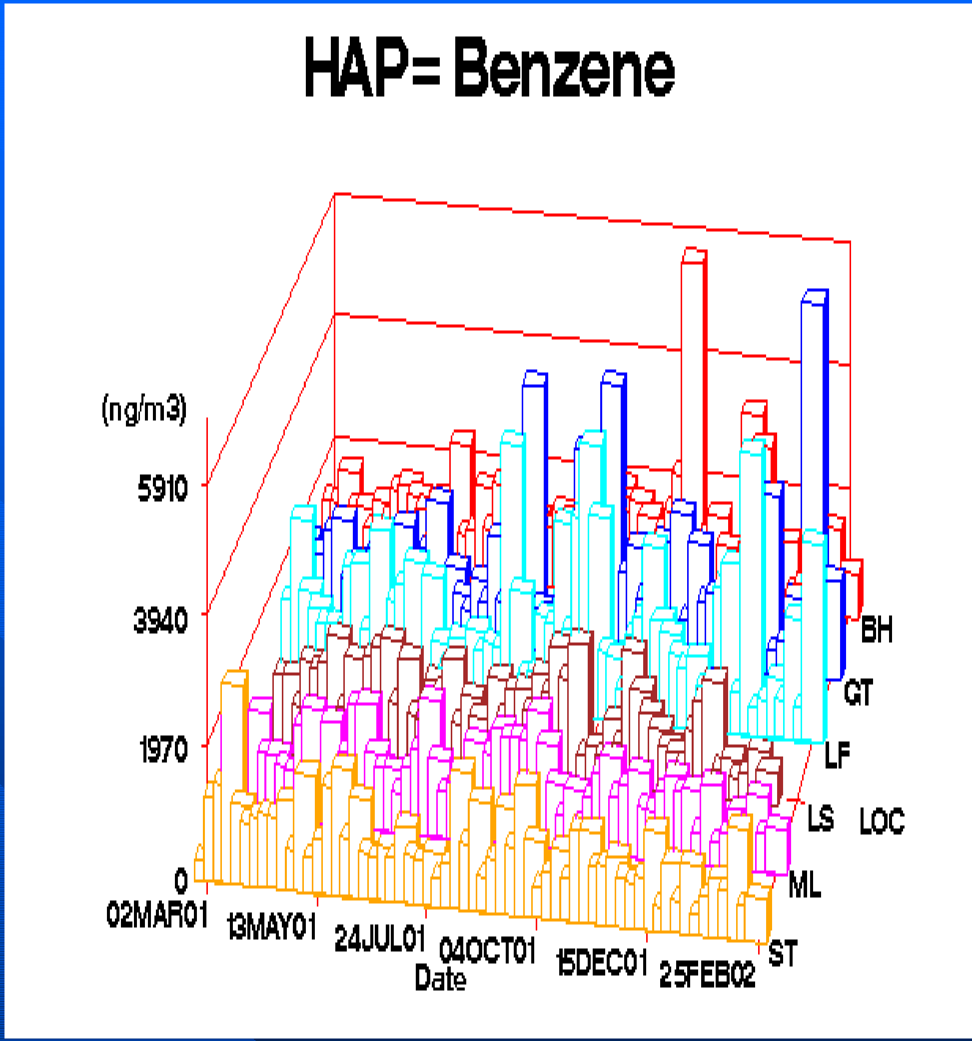


Analysis Variable : conc (ng/m3)								
loc	N	Mean	Median	Std Dev	5th Pctl	25th Pctl	75th Pctl	95th Pctl
BH	61	1496.267	1356.780	629.613	685.302	1078.102	1778.333	2680.969
GT	57	1851.252	1835.768	293.512	1405.833	1621.916	1987.864	2430.344
LF	59	1779.106	1748.336	592.535	801.819	1358.802	2252.137	2668.214
LS	54	1735.644	1755.707	206.882	1412.172	1546.587	1892.829	2096.392
ML	60	1980.566	1839.233	499.901	1282.546	1663.255	2231.759	2916.920
ST	61	1684.239	1601.409	524.652	1027.754	1241.419	1999.404	2699.378

Analysis Variable : conc (ng/m3)								
loc	N	Mean	Median	Std Dev	5th Ptcl	25th Pctl	75th Pctl	95th Pctl
BH	58	1718.027	1596.687	906.192	405.313	1105.399	2333.620	3439.018
GT	59	1430.357	1228.221	861.536	319.337	736.933	1965.153	2923.166
LF	59	1093.595	1105.399	560.853	245.644	614.110	1473.865	2087.975
LS	57	1040.756	859.755	775.221	147.387	491.288	1412.454	2579.264
ML	54	1260.746	1142.245	651.410	356.184	736.933	1719.509	2579.264
ST	61	1339.163	1314.196	647.572	577.264	798.344	1596.687	2456.442

Concentration of VOCs

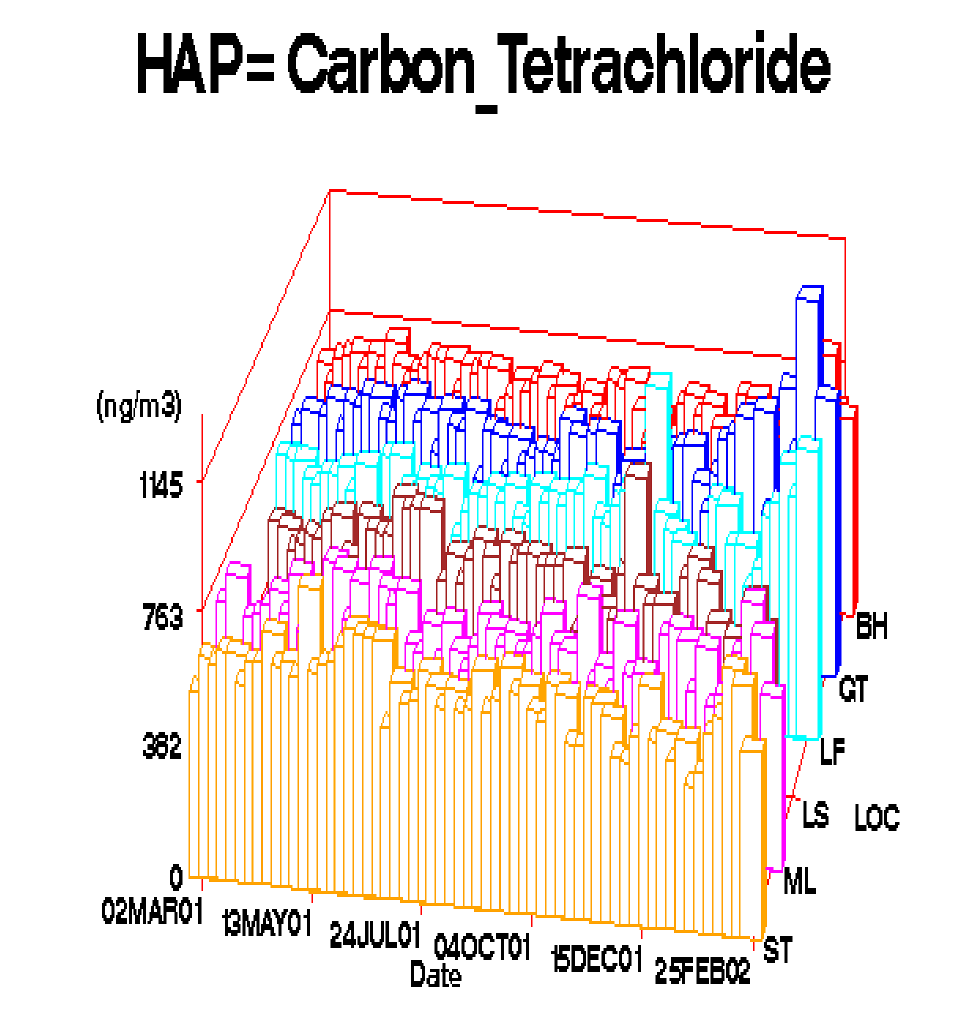




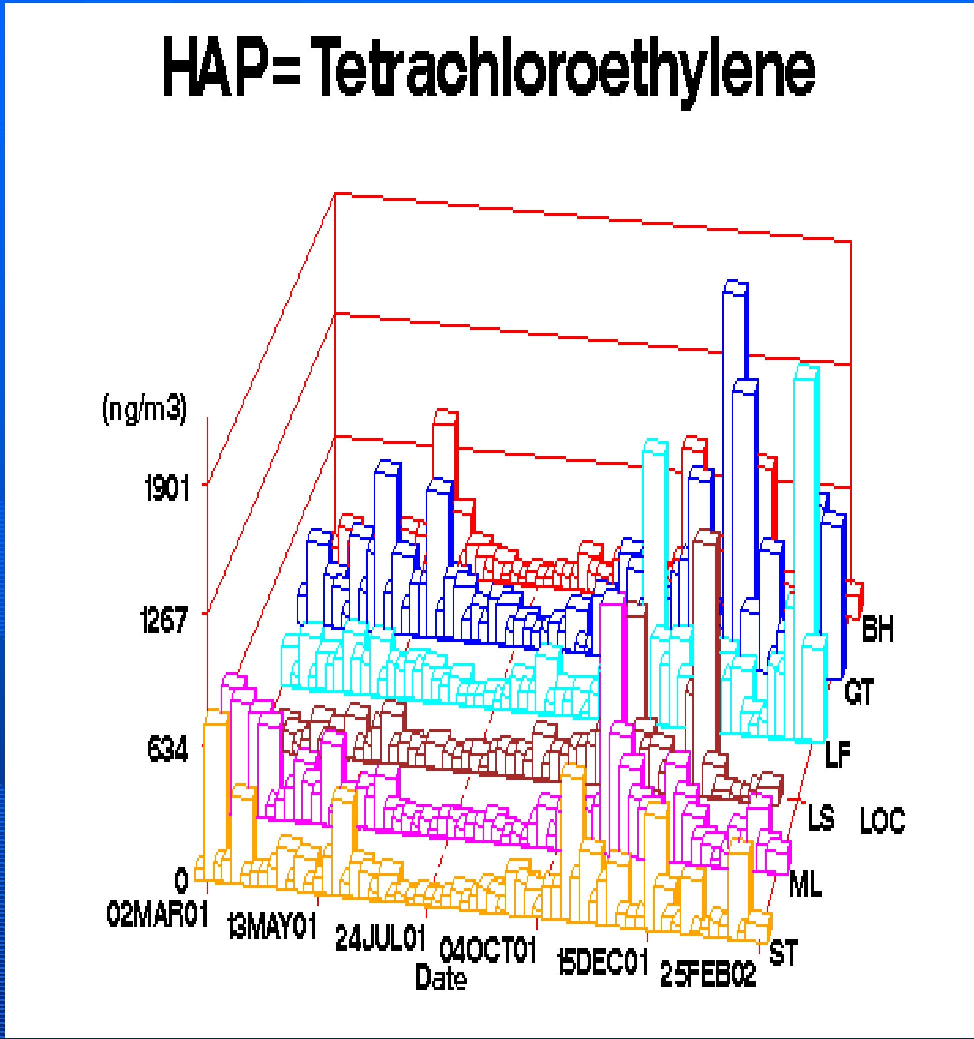
Analysis Variable : conc (ng/m3)								
loc	N	Mean	Median	Std Dev	5th Ptcl	25th Pctl	75th Pctl	95th Pctl
BH	58	1329.785	1081.227	865.329	360.409	883.002	1621.840	3423.885
GT	59	1202.178	955.084	747.593	378.429	720.818	1441.636	2703.067
LF	60	1182.742	1081.227	466.093	621.706	901.022	1441.636	2117.403
LS	57	1279.136	1081.227	795.357	540.613	901.022	1441.636	2522.863
ML	56	1138.506	1081.227	558.323	540.613	901.022	1261.431	1982.249
ST	61	1365.714	1189.350	586.492	720.818	1063.207	1621.840	2342.658

Analysis Variable : conc (ng/m3)								
loc	N	Mean	Median	Std Dev	5th Ptcl	25th Pctl	75th Pctl	95th Pctl
BH	61	1182.456	1067.024	759.777	511.149	734.777	1380.103	2172.384
GT	58	1413.175	1177.170	1046.616	360.999	702.830	1593.409	4170.211
LF	59	1567.846	1300.236	984.465	508.977	936.042	2019.040	4169.061
LS	55	1150.011	1182.033	498.697	453.645	734.777	1559.334	2086.246
ML	60	1108.499	1072.530	439.687	480.800	761.644	1471.152	1900.836
ST	61	1024.504	894.511	506.699	447.256	670.883	1297.840	1948.757

Concentration of VOCs

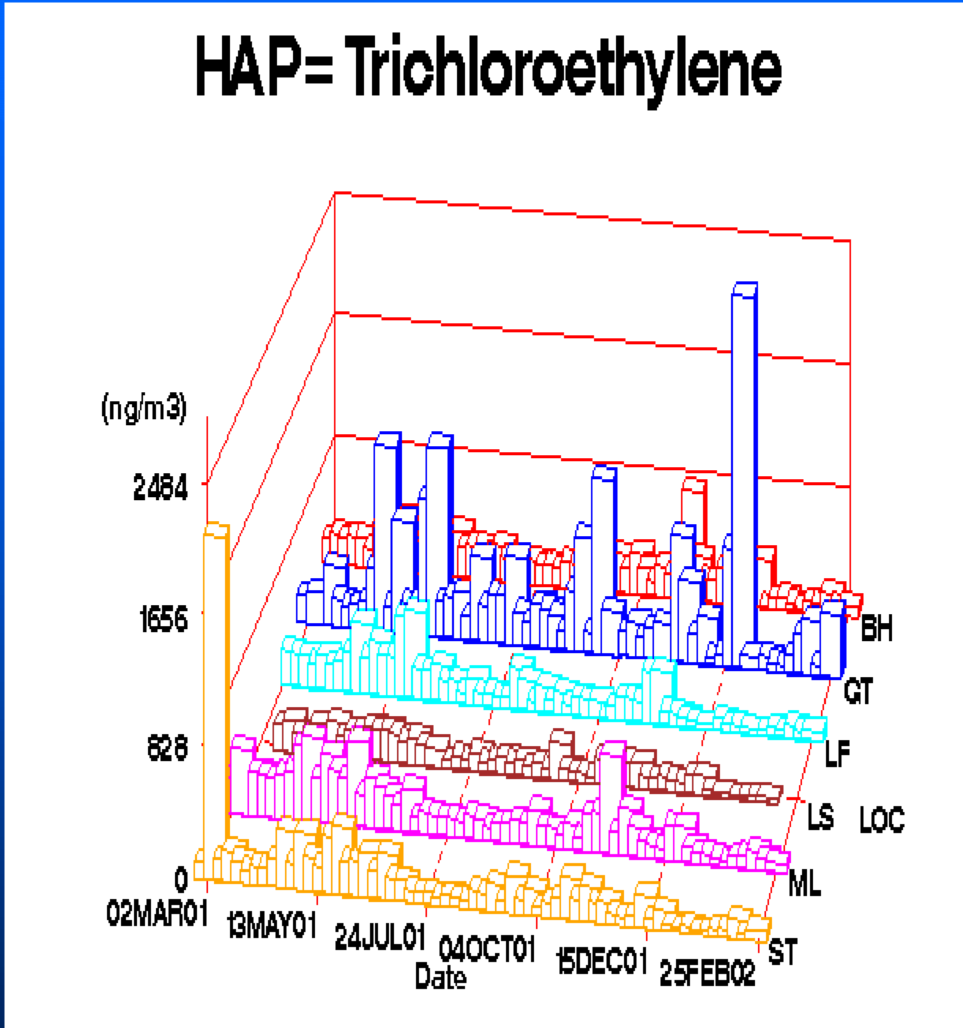


Analysis Variable : conc (ng/m3)								
loc	N	Mean	Median	Std Dev	5th Pctl	25th Pctl	75th Pctl	95th Pctl
BH	61	600.904	610.168	65.174	488.904	569.556	643.504	673.072
GT	57	644.310	649.420	112.013	475.180	580.995	691.943	842.912
LF	59	638.013	638.474	99.023	460.238	583.748	684.621	824.041
LS	53	624.685	635.074	97.170	454.541	556.385	681.891	768.723
ML	60	605.304	610.017	88.556	466.736	543.154	674.126	759.785
ST	61	623.581	633.673	87.978	483.416	571.221	671.675	761.062

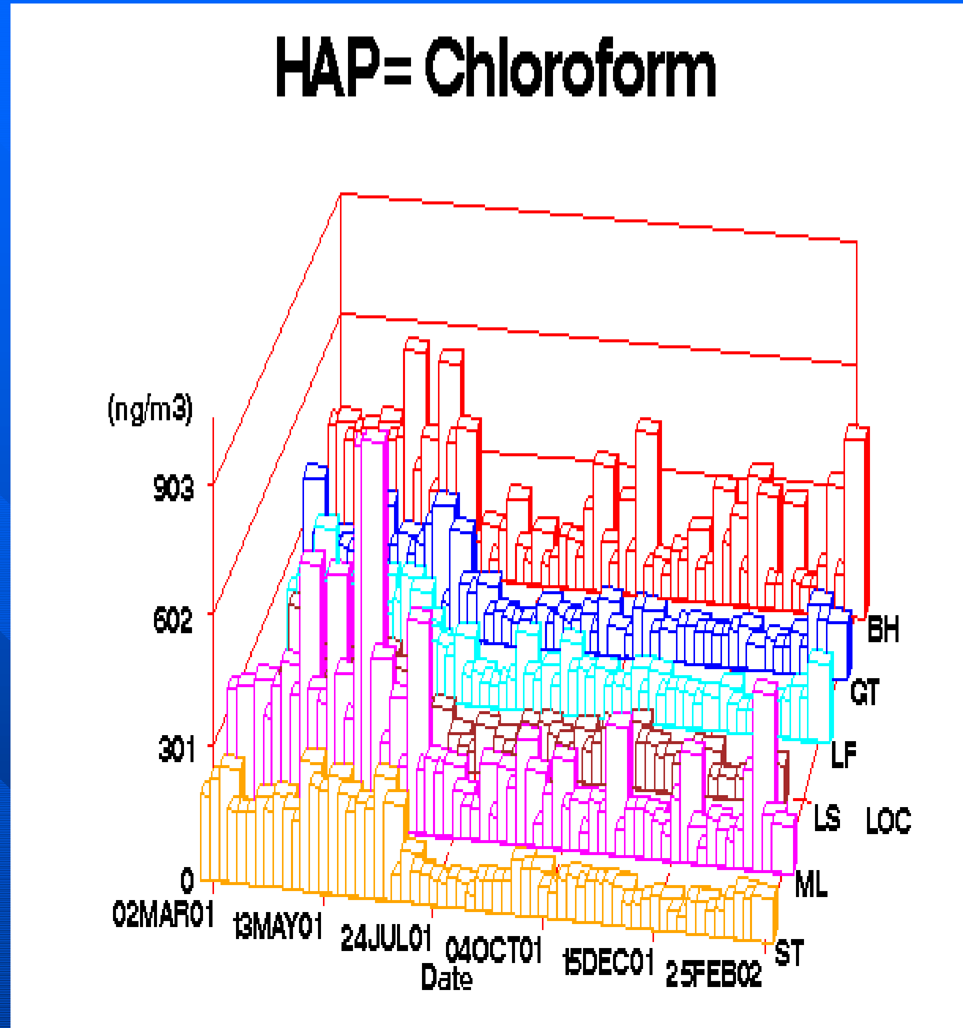


Analysis Variable : conc (ng/m3)								
loc	N	Mean	Median	Std Dev	5th Pctl	25th Pctl	75th Pctl	95th Pctl
BH	61	151.639	104.743	162.665	40.694	67.824	154.705	538.755
GT	57	338.337	236.028	335.259	67.824	138.443	406.945	939.308
LF	59	244.047	172.809	288.832	51.885	89.632	288.046	664.676
LS	53	166.036	108.858	200.615	30.811	78.337	186.140	506.344
ML	60	204.161	132.257	200.999	38.274	78.337	240.285	577.734
ST	61	146.026	81.389	158.430	26.451	46.799	166.746	460.824

Concentration of VOCs

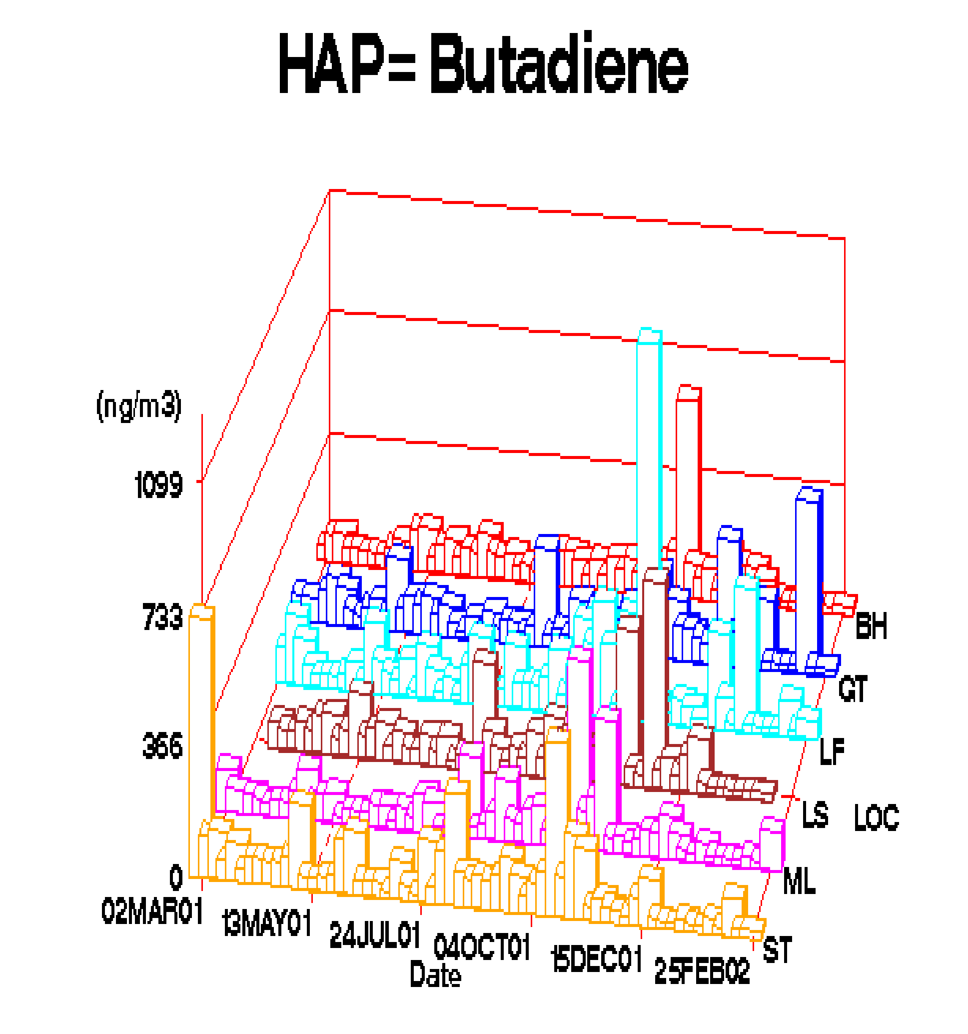


Analysis Variable : conc (ng/m3)								
loc	N	Mean	Median	Std Dev	5th Pctl	25th Pctl	75th Pctl	95th Pctl
BH	61	189.600	177.350	106.382	64.491	139.300	228.692	306.331
GT	57	381.490	243.775	406.781	59.117	166.386	407.820	1246.822
LF	58	164.518	141.749	121.315	38.122	77.389	219.376	472.503
LS	53	119.310	116.428	58.445	32.245	77.389	168.309	219.376
ML	60	204.156	153.679	134.294	59.117	105.752	274.220	518.909
ST	61	173.543	126.563	279.202	32.245	65.781	185.626	371.252



Analysis Variable : conc (ng/m3)								
loc	N	Mean	Median	Std Dev	5th Pctl	25th Pctl	75th Pctl	95th Pctl
BH	61	199.026	136.957	129.868	57.276	89.645	317.370	403.484
GT	57	131.656	97.115	77.580	55.774	72.214	190.422	312.488
LF	59	139.567	109.566	79.708	58.591	79.204	200.187	292.957
LS	53	119.935	108.541	67.943	44.822	70.310	158.657	234.366
ML	60	220.838	160.540	181.039	55.887	103.407	297.840	595.679
ST	61	126.170	94.625	73.018	54.783	70.000	188.469	263.857

Concentration of VOCs



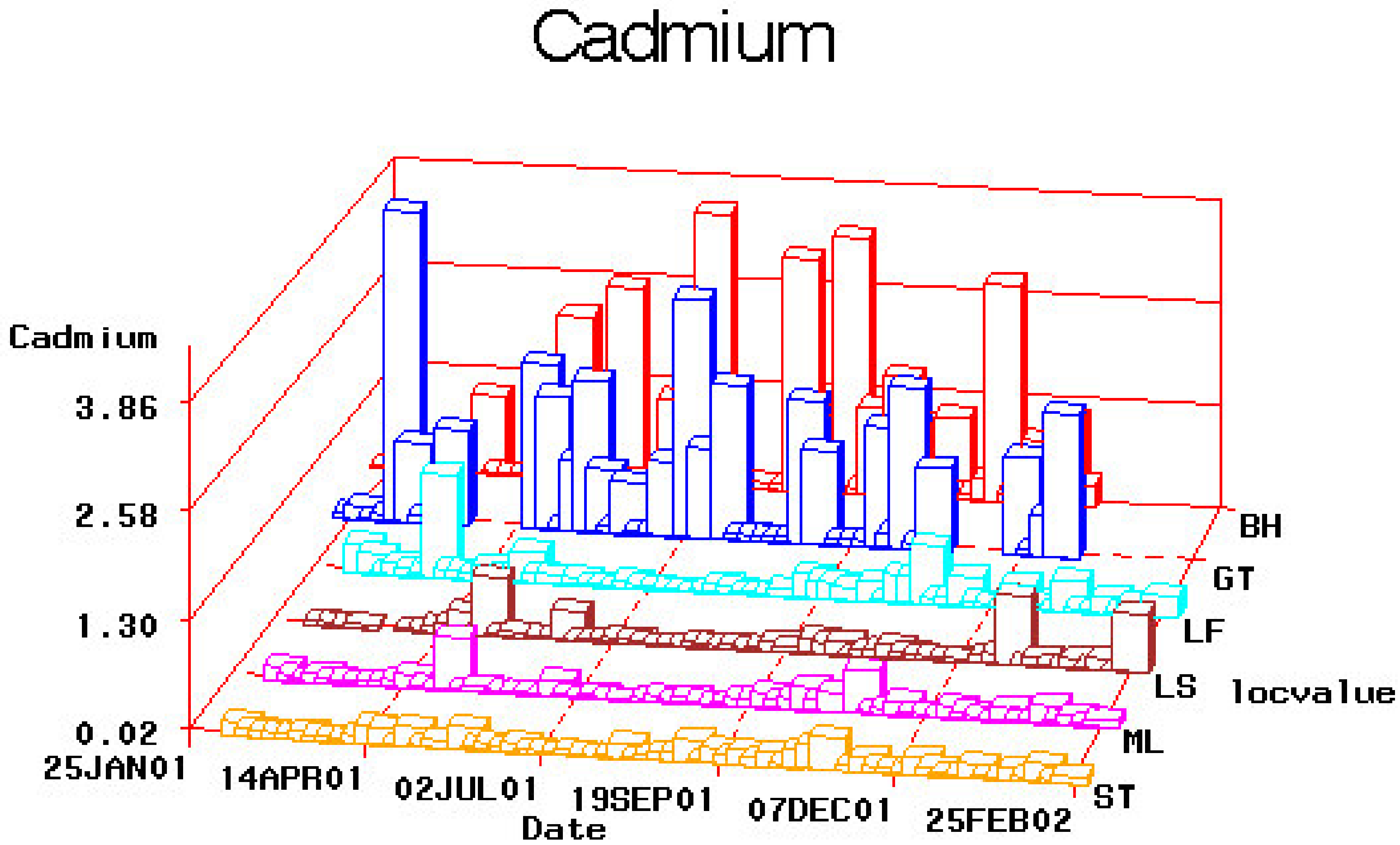
Analysis Variable : conc (ng/m3)								
loc	N	Mean	Median	Std Dev	5th Ptcl	25th Pctl	75th Pctl	95th Pctl
BH	61	77.841	63.505	74.899	22.123	44.245	95.128	132.736
GT	58	98.519	75.217	88.534	22.123	44.245	110.613	292.504
LF	59	121.586	73.308	158.619	22.123	41.157	154.859	336.694
LS	55	94.560	73.005	99.297	22.123	44.245	109.103	310.439
ML	60	78.436	54.201	83.018	22.123	39.736	81.993	205.826
ST	61	100.648	70.793	114.909	22.123	39.821	115.571	239.388

Quality Control

- Limit of detection

	ICP-MS	XRF	XRF/ ICP-MS
	ng/m^3	ng/m^3	
Arsenic	0.05	0.99	21.5
Cadmium	0.03	4.21	145.2
Chromium	0.49	0.63	1.3
Lead	0.35	2.20	6.3
Manganese	0.33	0.92	2.8
Nickel	0.19	0.50	2.7

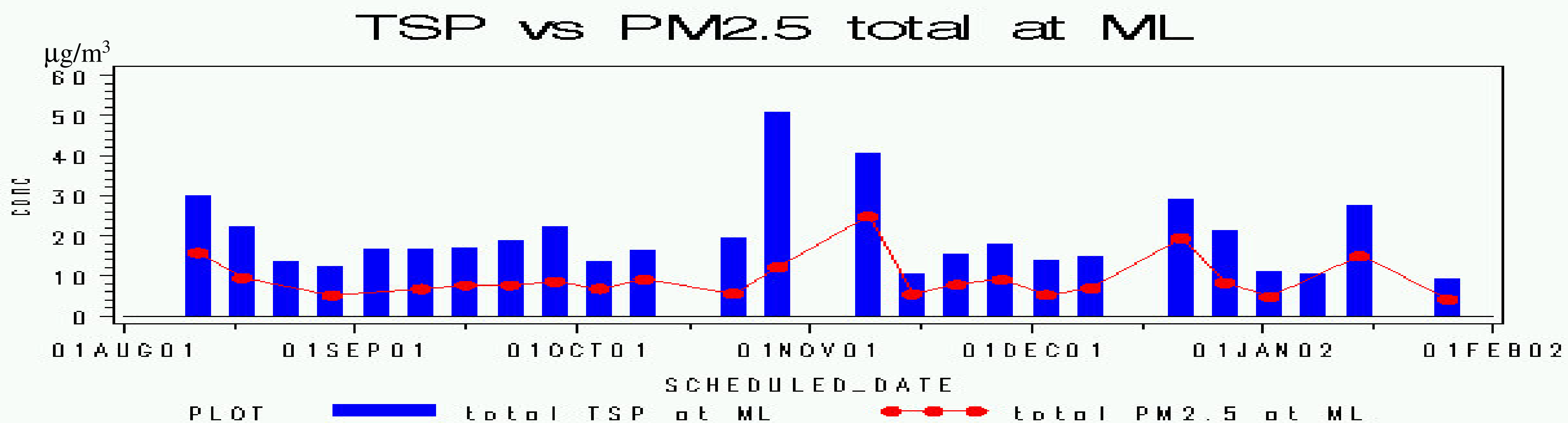
$PM_{2.5}$ metals at BH & GT vs. TSP metals at other four sites

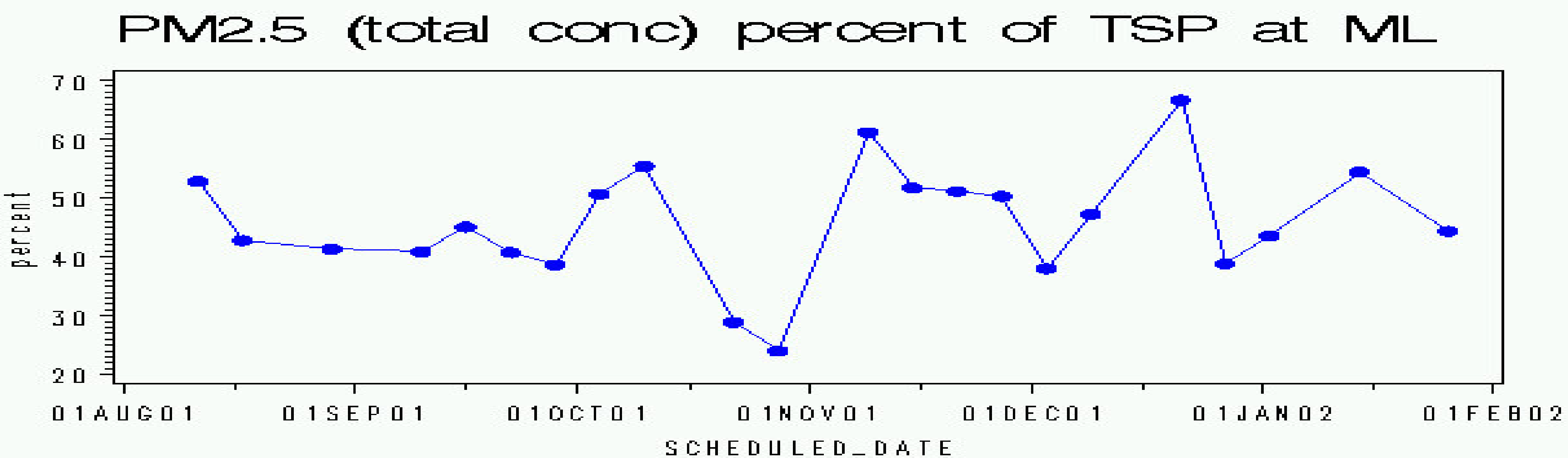


Comparisons of collocated $PM_{2.5}$ and TSP samples at Maple Leaf (ML)

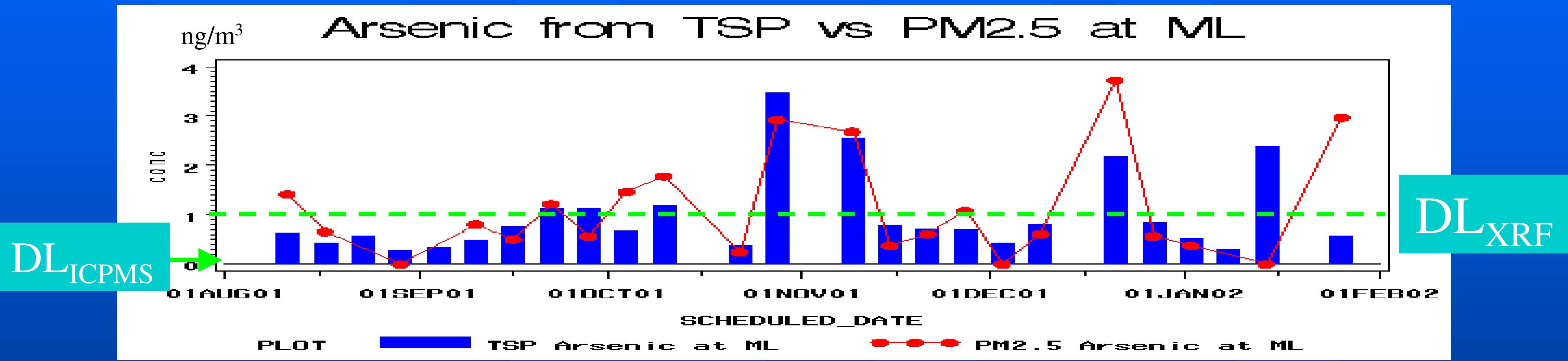
- Collocated $PM_{2.5}$ and TSP samplers at ML, Aug 2001 to Jan 2002
- $PM_{2.5}$ samples: 1 ft^3/min, 47-mm Teflon filter, analyzed with XRF
- TSP samples: 40 ft^3/min, 8"x10" quartz filter, part extracted and analyzed with ICP-MS

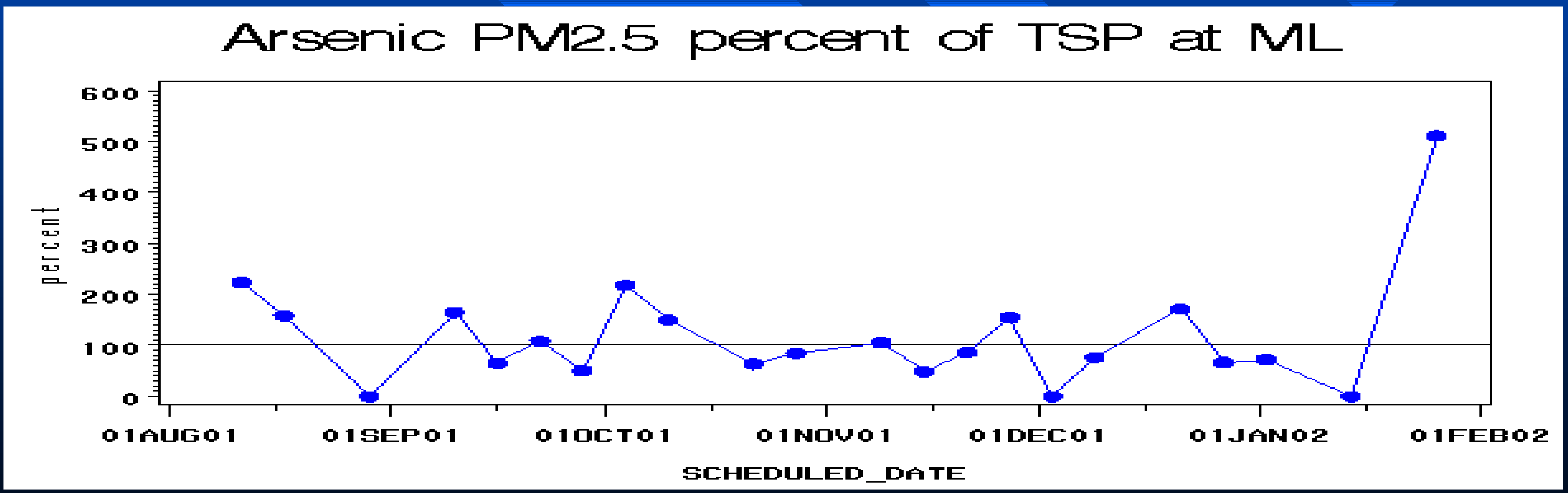
TSP vs. $PM_{2.5}$ mass concentrations



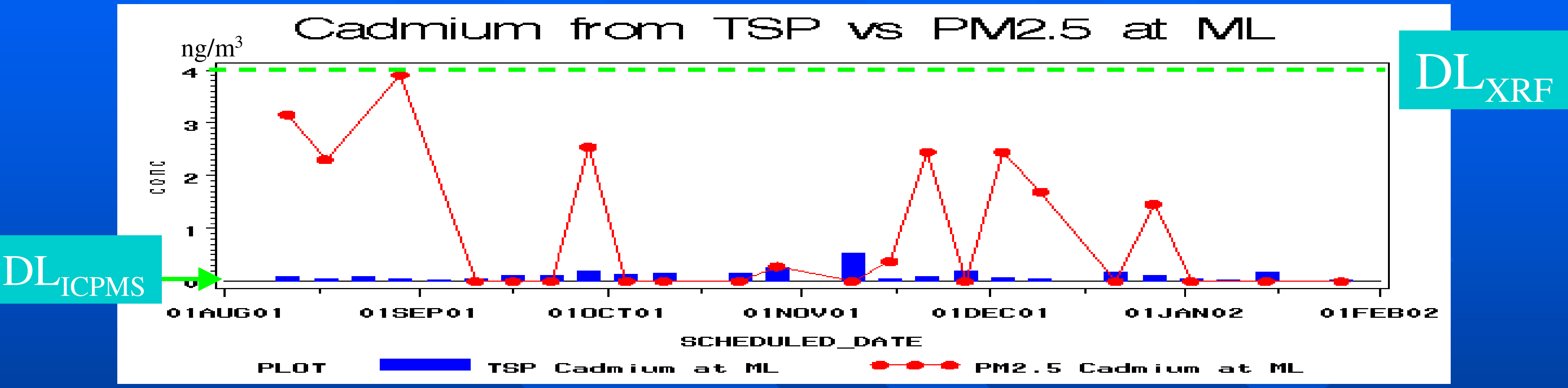


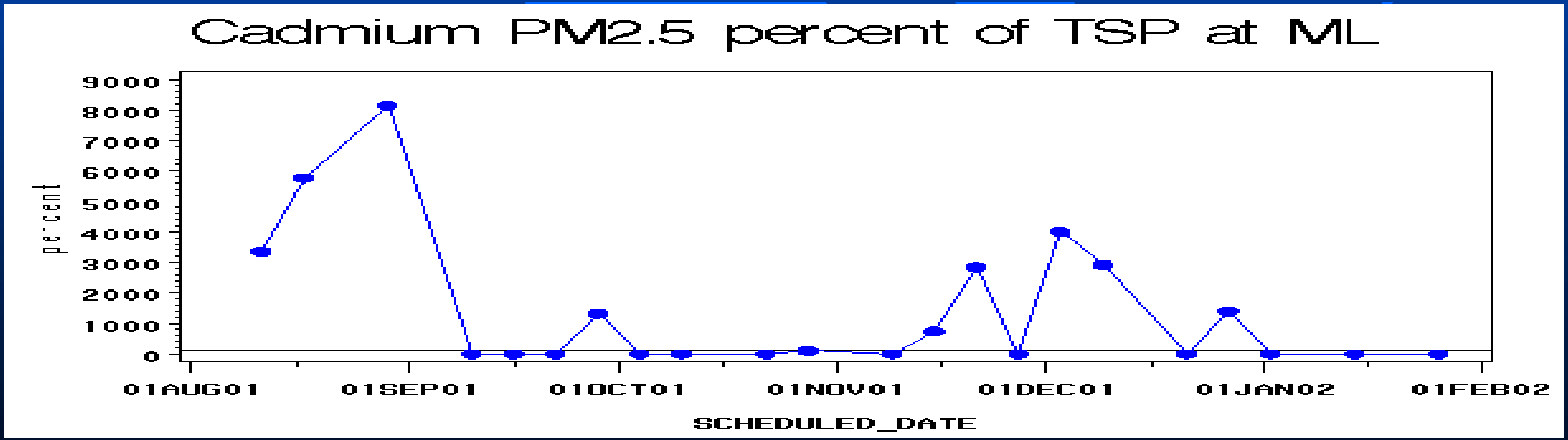
$As_{2.5}$ vs. As_{TSP}



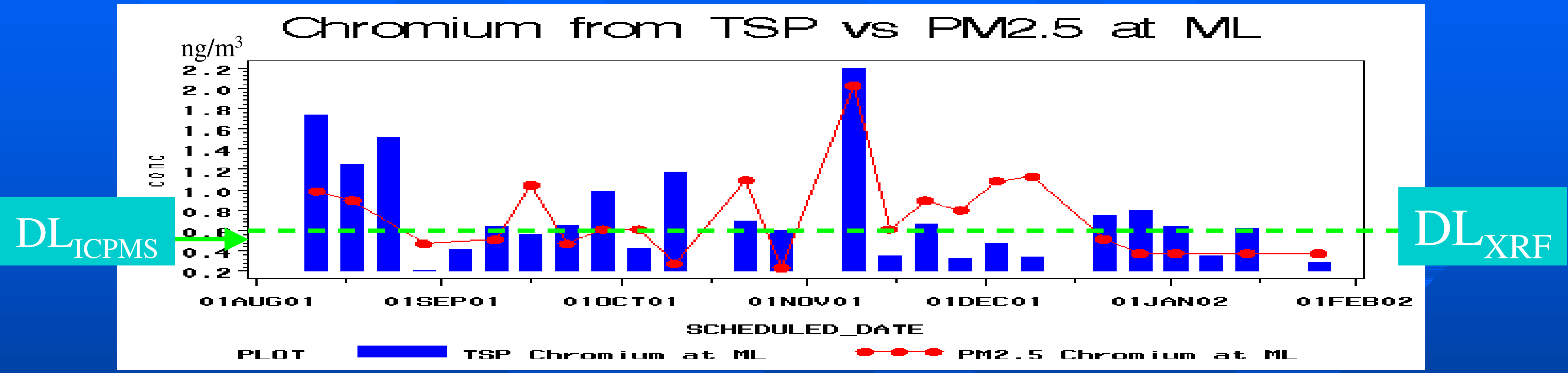


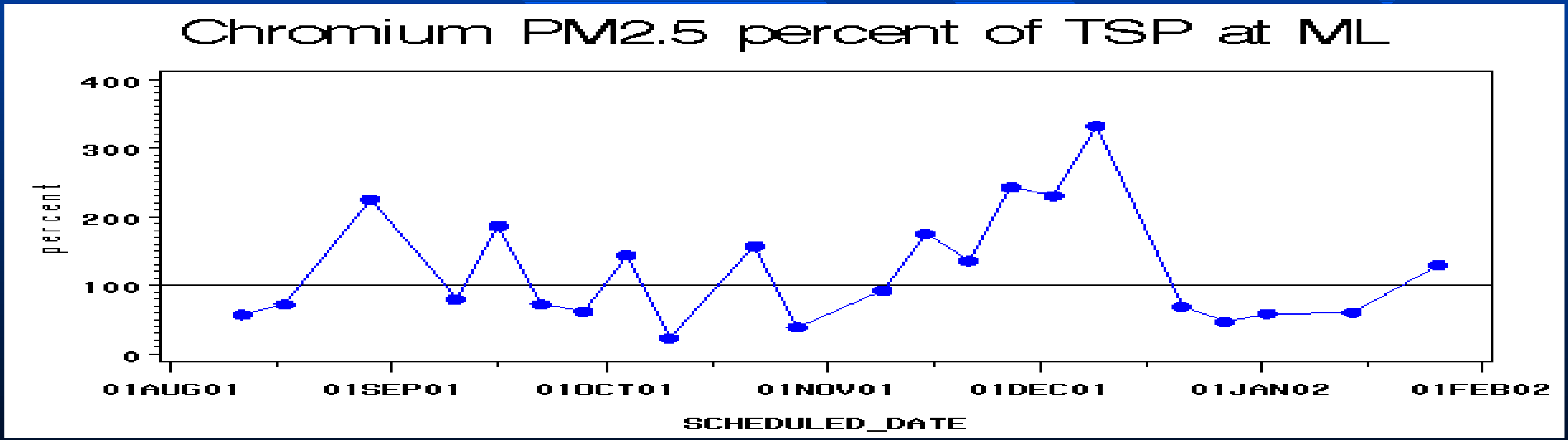
$Cd_{2.5}$ vs. Cd_{TSP}



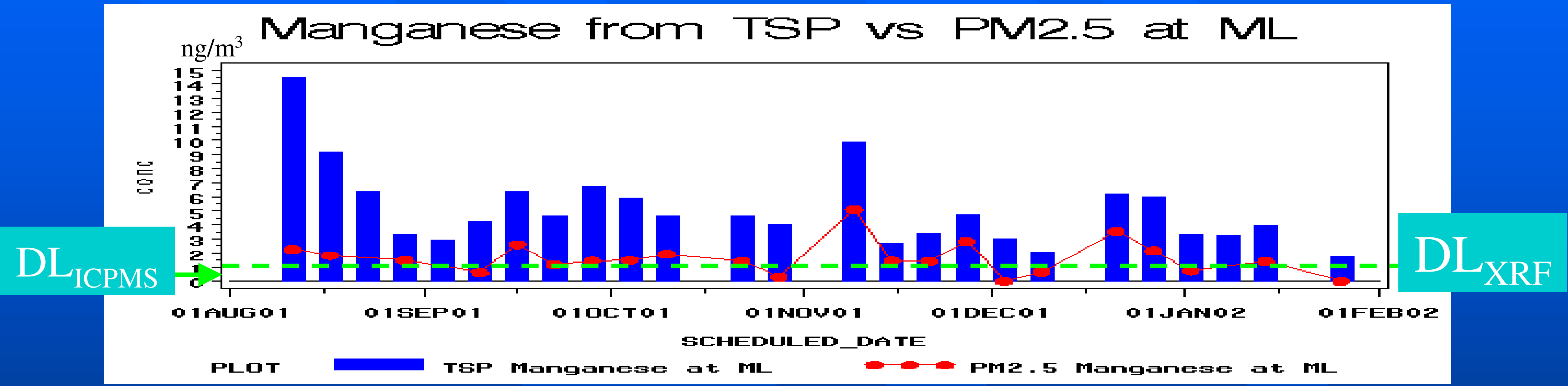


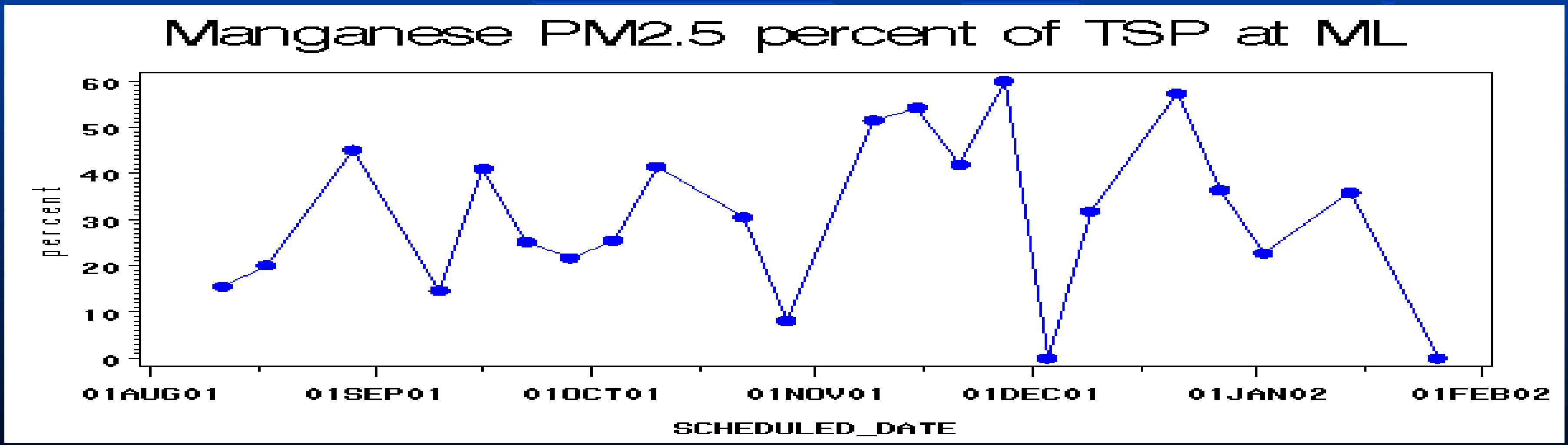
$Cr_{2.5}$ vs. Cr_{TSP}



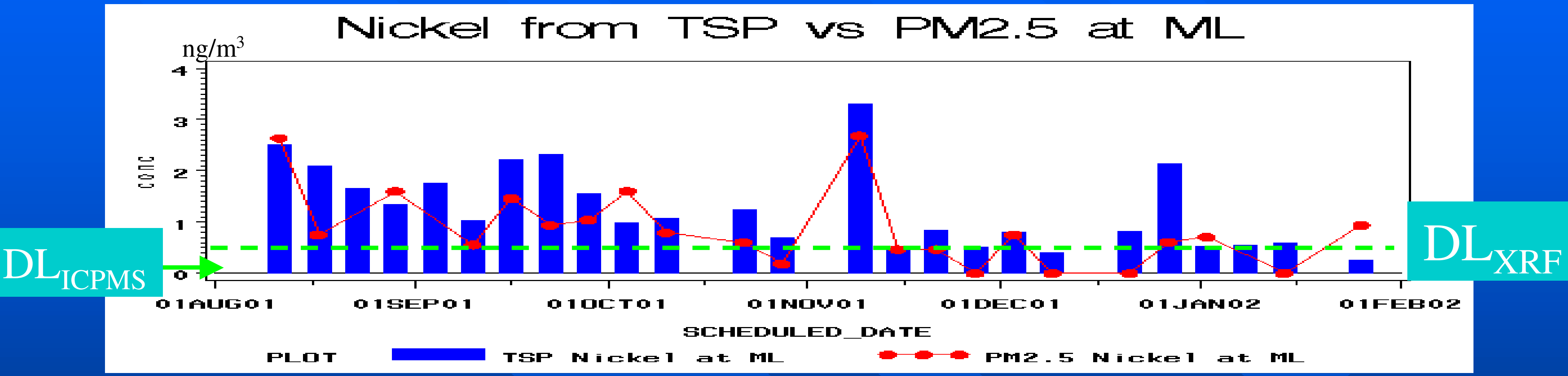


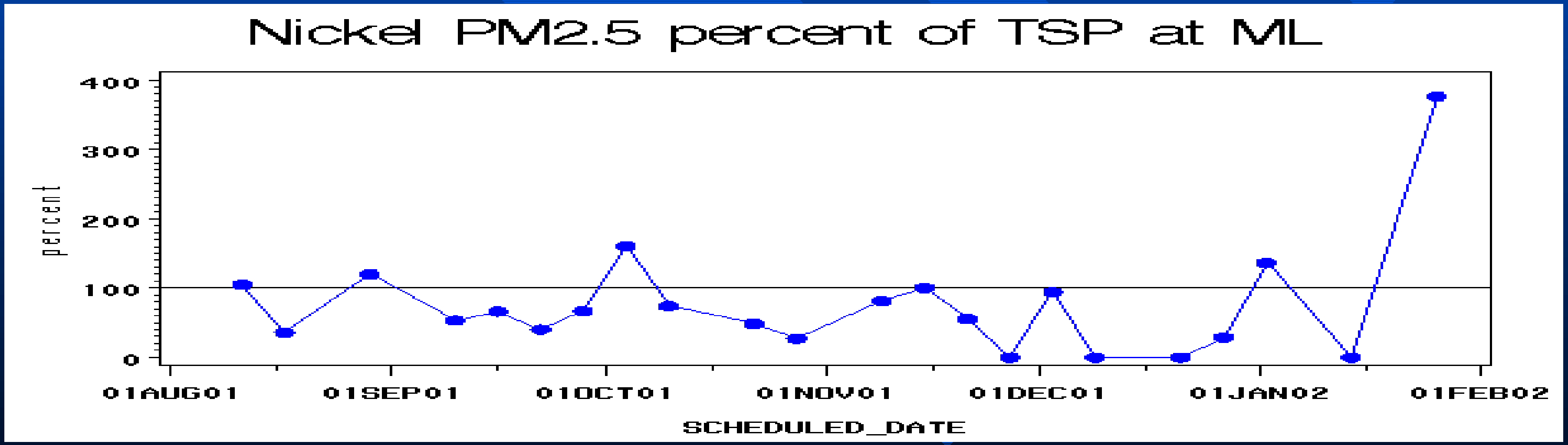
$Mn_{2.5}$ vs. Mn_{TSP}



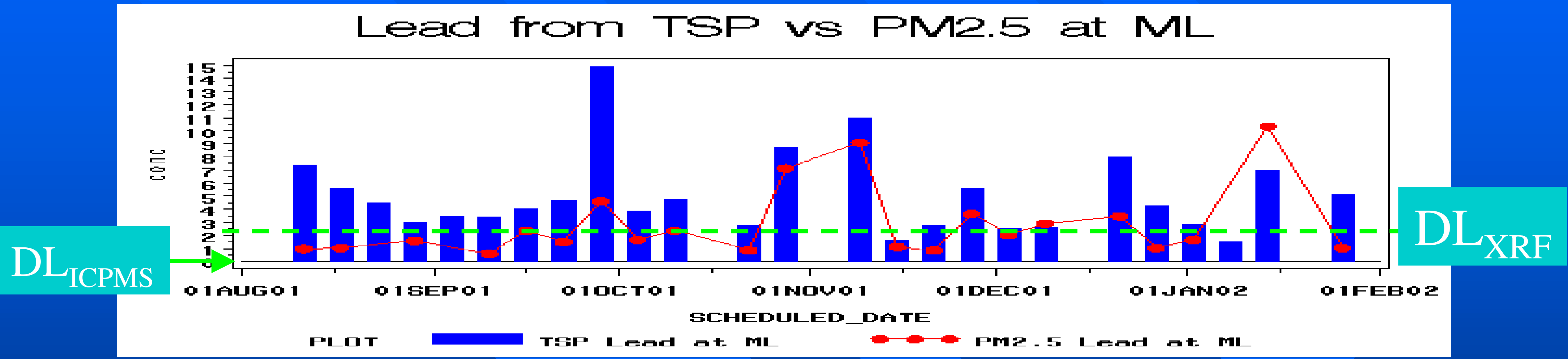


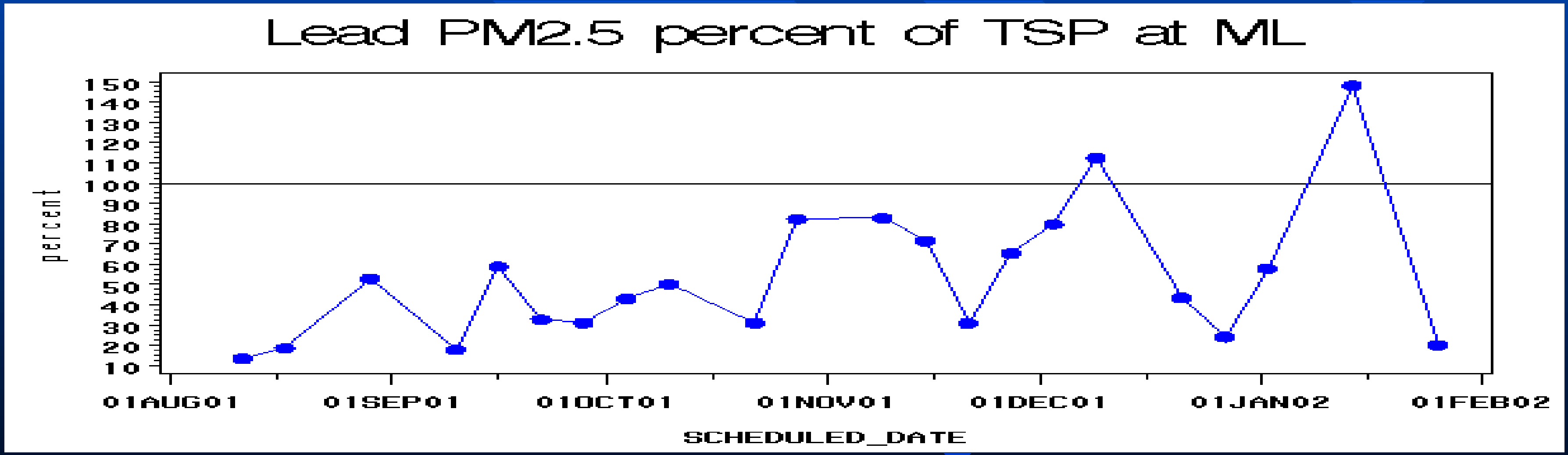
$Ni_{2.5}$ vs. Ni_{TSP}





$Pb_{2.5}$ vs. Pb_{TSP}





Quality Control

- XRF and ICP-MS results are not comparable.
  1. PM mass concentrations are less reliable for quartz than for Teflon filters
  2. Some analytical issues (recovery and digestion) related to ICP-MS analysis of quartz filters
  3. Detection limits are much higher for XRF
  4. Many metal concentrations are below the limit of detection for XRF, esp. Cd, Cr, and As.
  5. The ratio of $PM_{2.5}$ to TSP is not constant. This holds true to individual metal components.
- Data analysis on metals was thus performed separately for BH/GT and the other sites.

Data Analysis

Temporal and Spatial Variations

- Use ANOVA to examine the spatial pattern of metals and VOCs.
  - Are HAPs at some sites are much higher than other sites?
- Use GLM to test for both temporal and spatial variations.
  - Is space/site more important than season (or vice versa) in terms of the total variation in HAPs measurements?
- Use PCA to test for groups of HAPs that behave similarly (spatially and temporally)

Analysis of Variance (ANOVA) Site Effect

- $\text{Log}(\text{Conc}_{ij}) = \mu + \text{Site}_j + \varepsilon_{ij}$

  Where μ is the overall mean,

  ε_{ij} is the residue error, and

- Site_j is the spatial (site) effect:
  - VOCs: j=1-6 sites
  - Metals: j=1-4 sites

    (Analysis results from $PM_{2.5}$ XRF vs. TSP ICP-MS are not comparable.)

ANOVA test of Sites

pvalue for overall ANOVA
ln_conc, alpha=0.05

Obs	hap	PROB	Significant
1	Arsenic	0.00022	*
2	Beryllium	0.00387	*
3	Cadmium	0.04265	*
4	Chromium	0.00009	*
5	Lead	0.00199	*
6	Manganese	0.17501	
7	Nickel	0.00000	*
8	Acetaldehyde	0.24799	
9	Benzene	0.00389	*
10	Butadiene	0.34994	
11	Carbon_Tetrachloride	0.11577	
12	Chloroform	0.00000	*
13	Dichloromethane	0.00000	*
14	Formaldehyde	0.00003	*
15	Tetrachloroethylene	0.00000	*
16	Trichloroethylene	0.00000	*

Hypothesis (H_o):

For Metals

H_o: $\mu_{LF} = \mu_{LS} = \mu_{ML} = \mu_{ST}$

H_A: $\mu_{LF}, \mu_{LS}, \mu_{ML}, \mu_{ST}$ are not all equal

Multiple Comparison between Sites Scheffe's method : Metals

Arsenic	LF	>	LS, ML, ST
Beryllium	LS, ST	>	ML
Cadmium			
Chromium	ST	>	LS, ML
Lead	LF	>	LS
Manganese			
Nickel	ML, ST	>	LF, LS

Multiple Comparison between Sites
Scheffe's method : VOCs

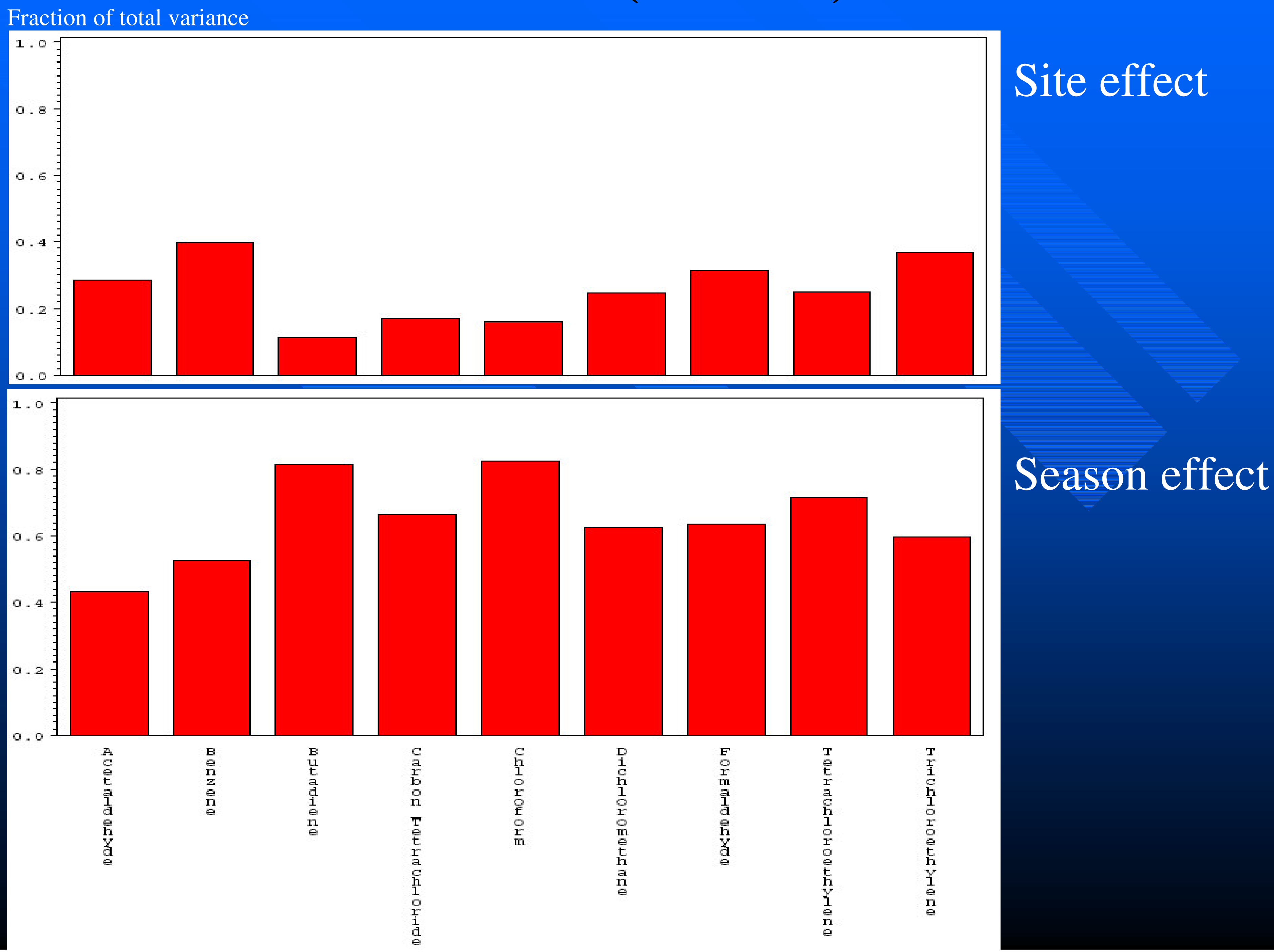
Acetaldehyde			
Benzene	LF	>	ST
Butadiene			
Carbon_Tetrachloride			
Chloroform	BH, ML	>	LS, ST, GT
Dichloromethane	GT, LF, LS, ML	>	BH
Formaldehyde	BH	>	LF, LS
Tetrachloroethylene	LF, GT	>	BH, LS, ST
Trichloroethylene	GT	>	BH, LF, LS, ML, ST (BH, ML > LS)

General Linear Model

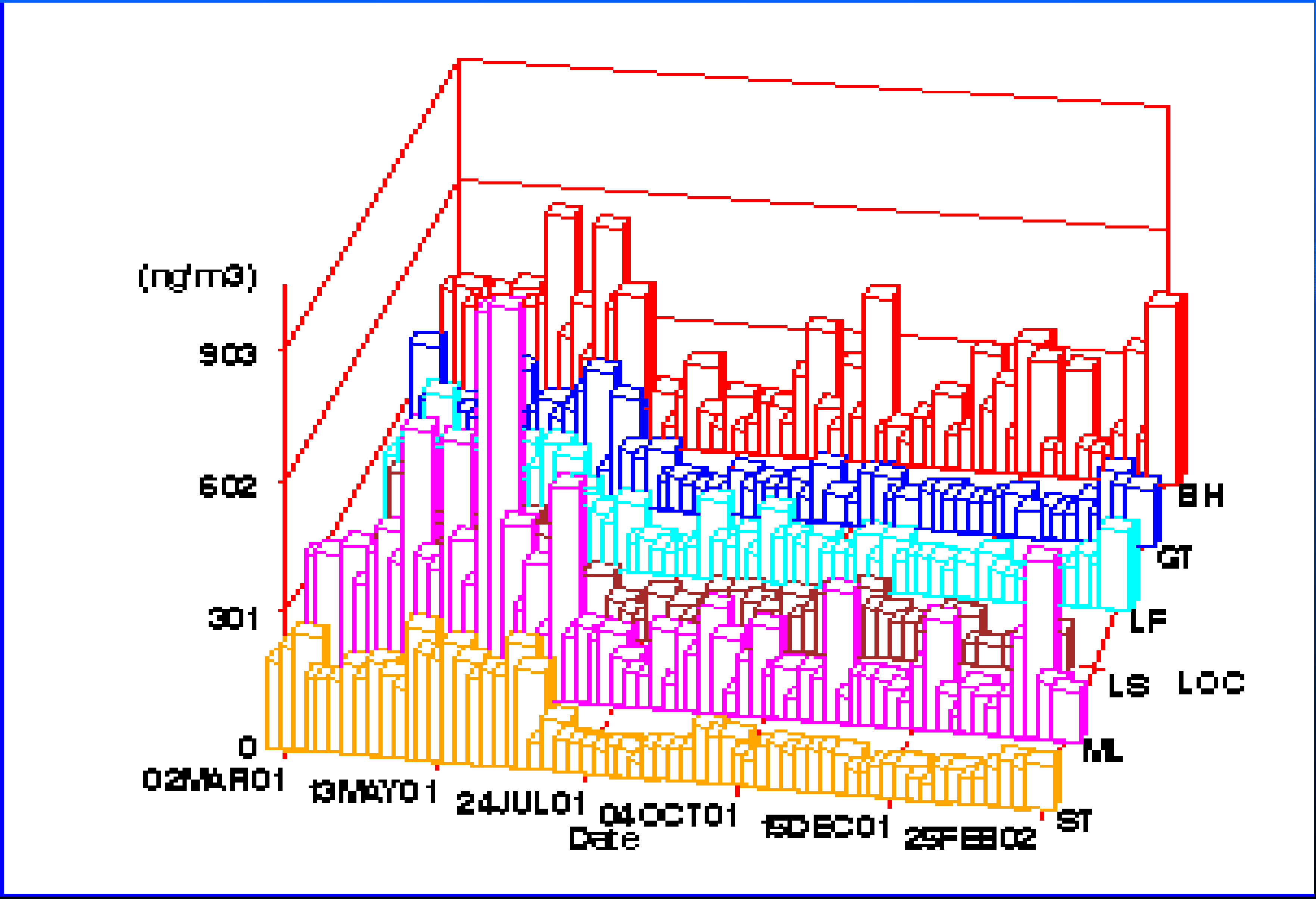
- $\text{Log}(\text{Conc}_{ij}) = \mu + \text{Season}_i + \text{Site}_j + \varepsilon_{ij}$
- Season: *i*=1-4
  - Season 1: spring (March, April, May 2001)
  - Season 2: summer
  - Season 3: fall
  - Season 4: winter
- Site: *j*=1-4 or 6
  - VOCs: 6 sites
  - Metals: 4 sites

    (to avoid issues regarding $PM_{2.5}$ XRF vs. TSP ICP-MS results)

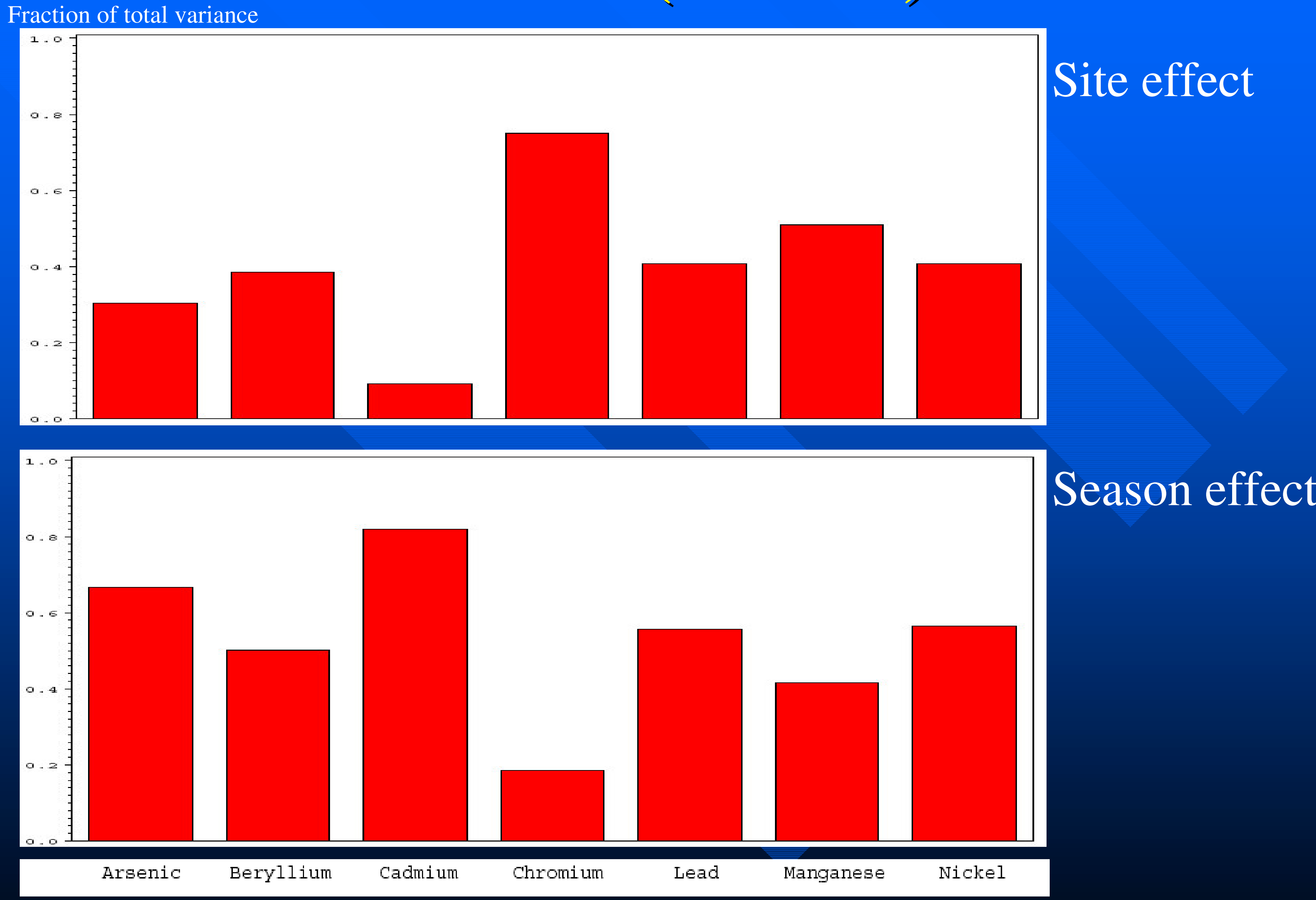
VOCs (6 sites)


Fraction of total variance
1.0
0.8
0.6
0.4
0.2
0.0
Site effect
Season effect
Acetaldehyde
Benzene
Butadiene
Carbon Tetrachloride
Chloroform
Dichloromethane
Formaldehyde
Tetrachloroethylene
Trichloroethylene

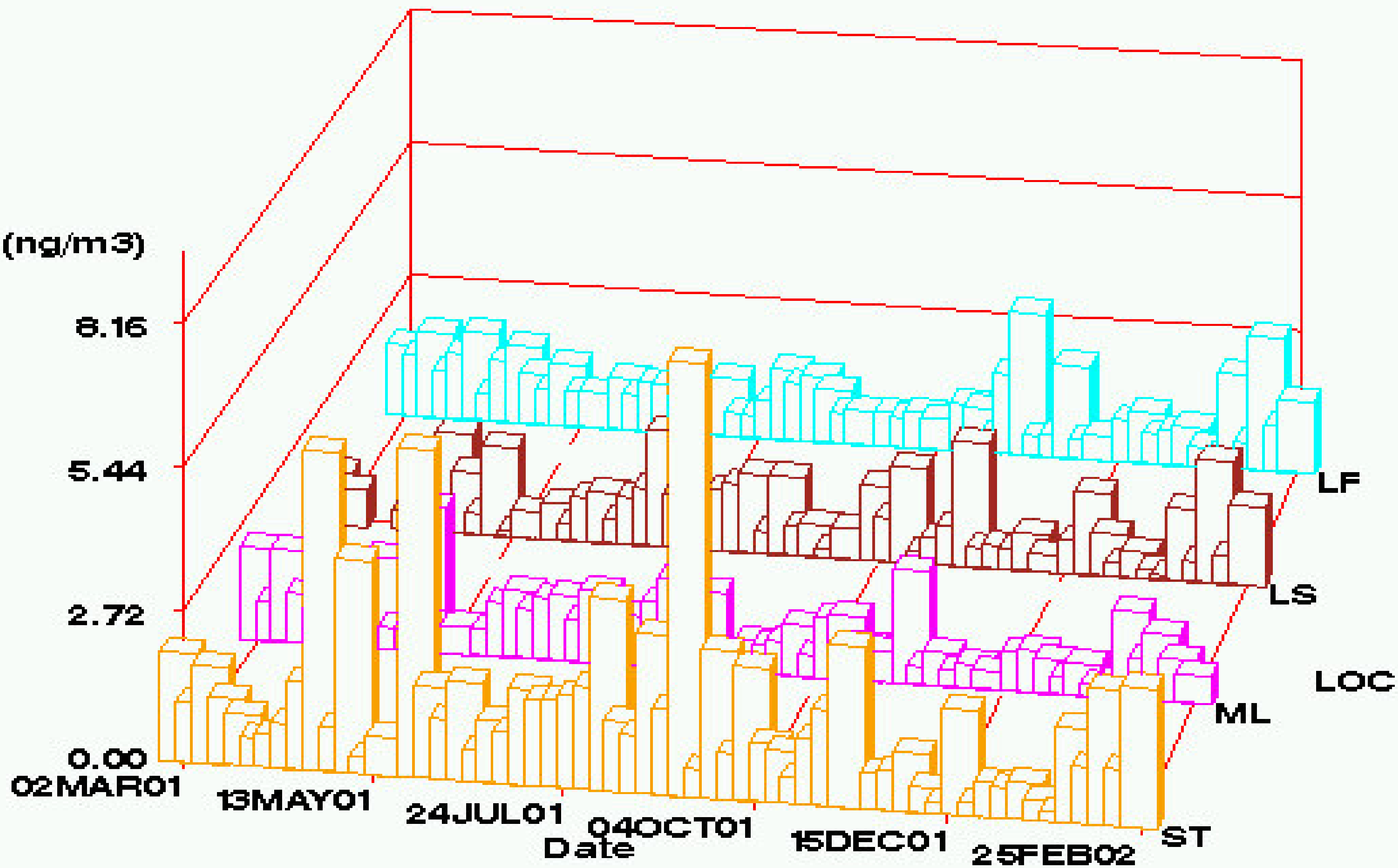
Chloroform
(site effect vs. season effect)



Metals (4 sites)



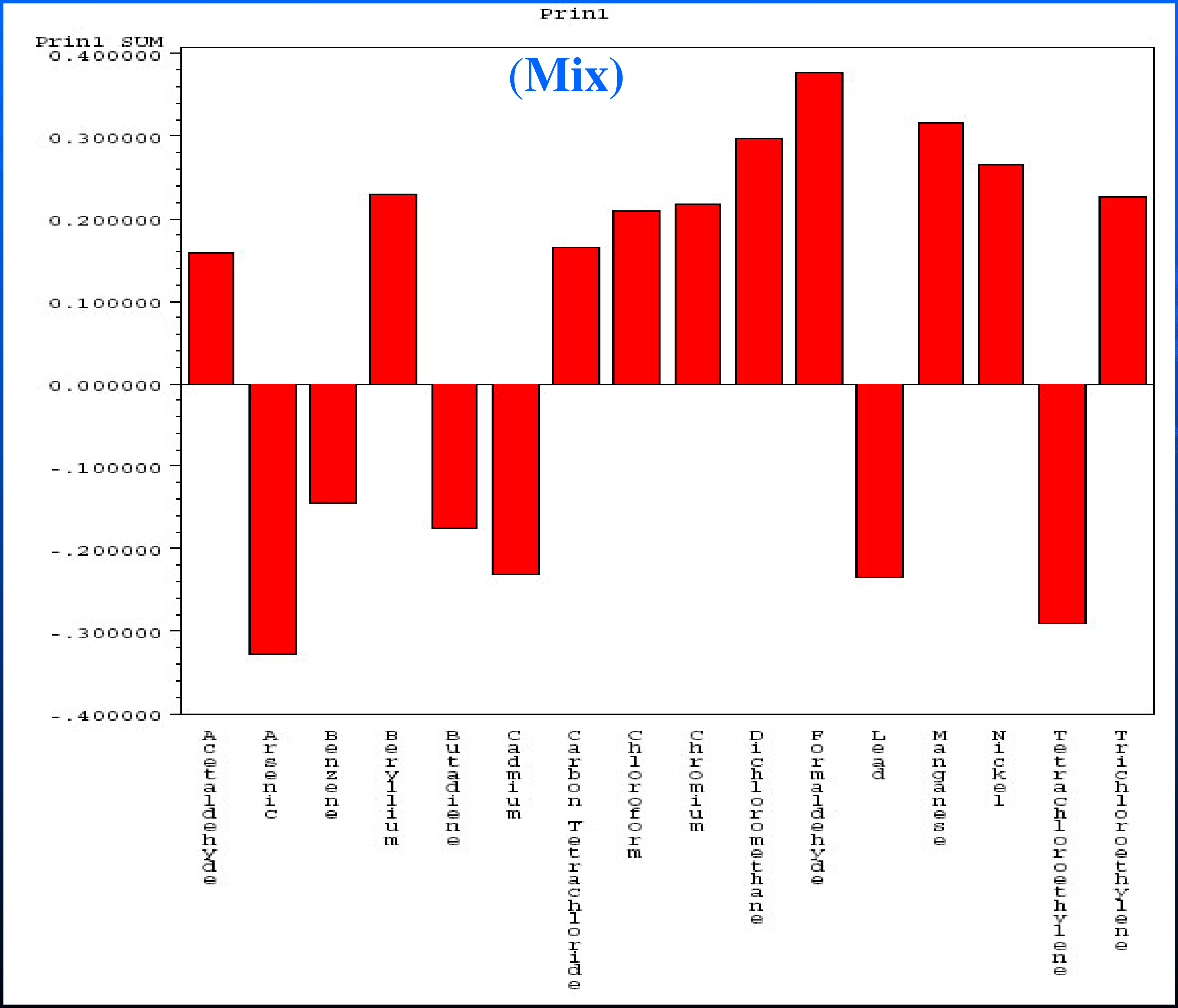
Cr (site effect vs. season effect)



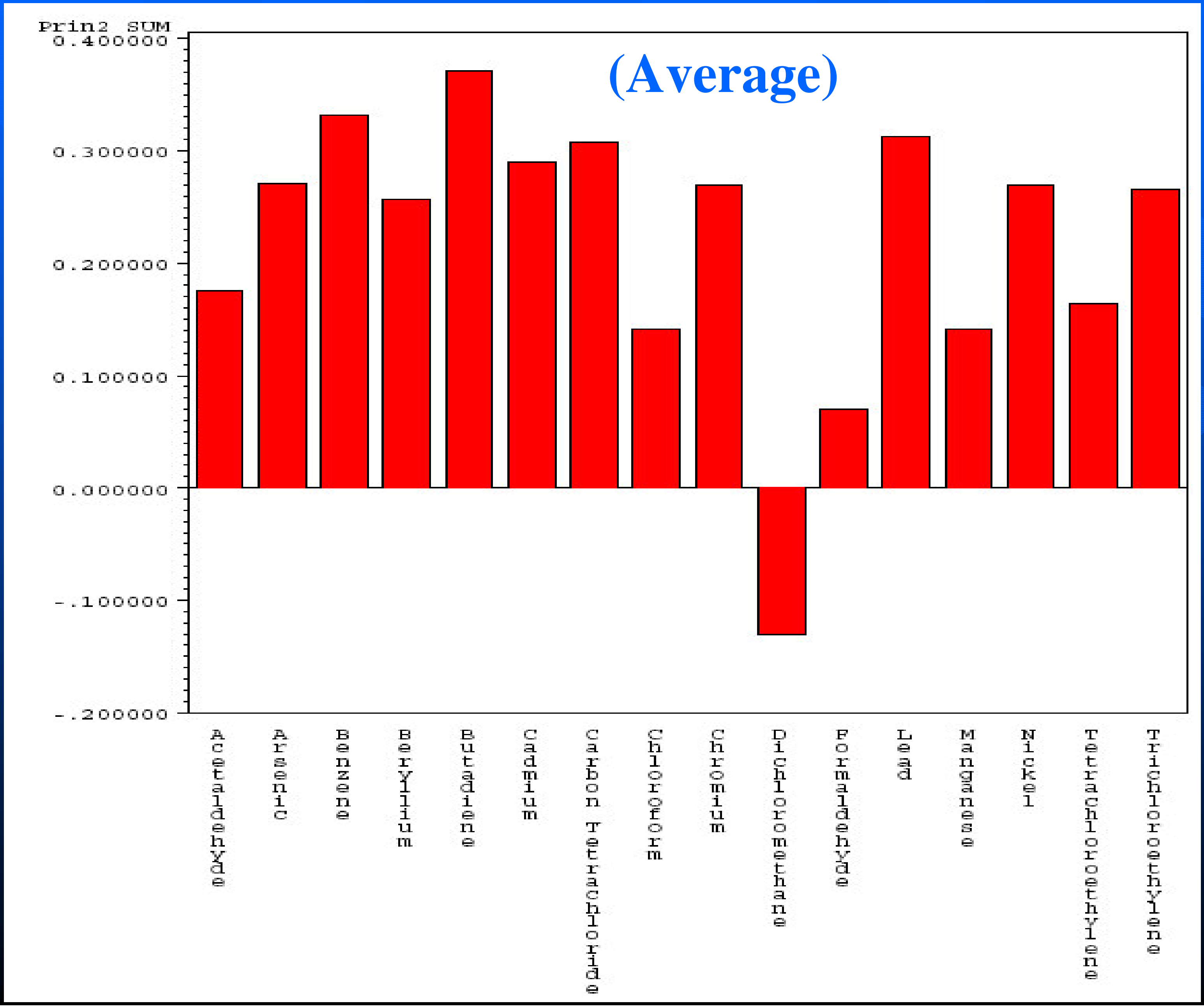
Principle Component Analysis (PCA)

- Calculate the PC as a liner combination of the original variables
  - PC = [eigenvector] * [concentration]
  - PCs are uncorrelated
  - PC1 accounts for as much of the variability in the data as possible
- PCA was run for all HAPs in 4 seasons and only 4 locations
- PCA was run again for VOCs only in 4 seasons and all 6 locations

Eigenvectors for PC1
4 locations, 4 Seasons, All HAPs

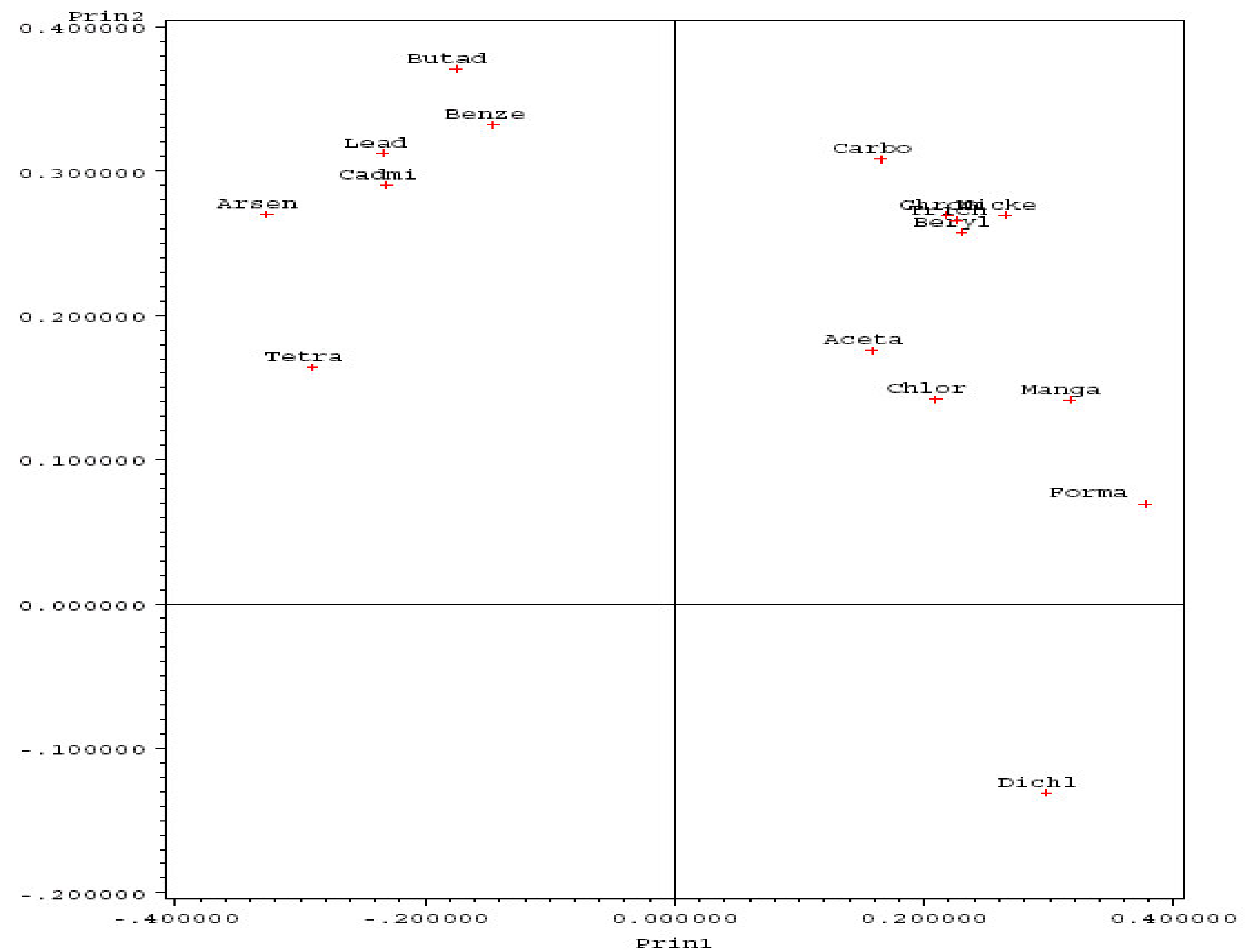


Eigenvectors for PC2
4 locations, 4 Seasons, All HAPs

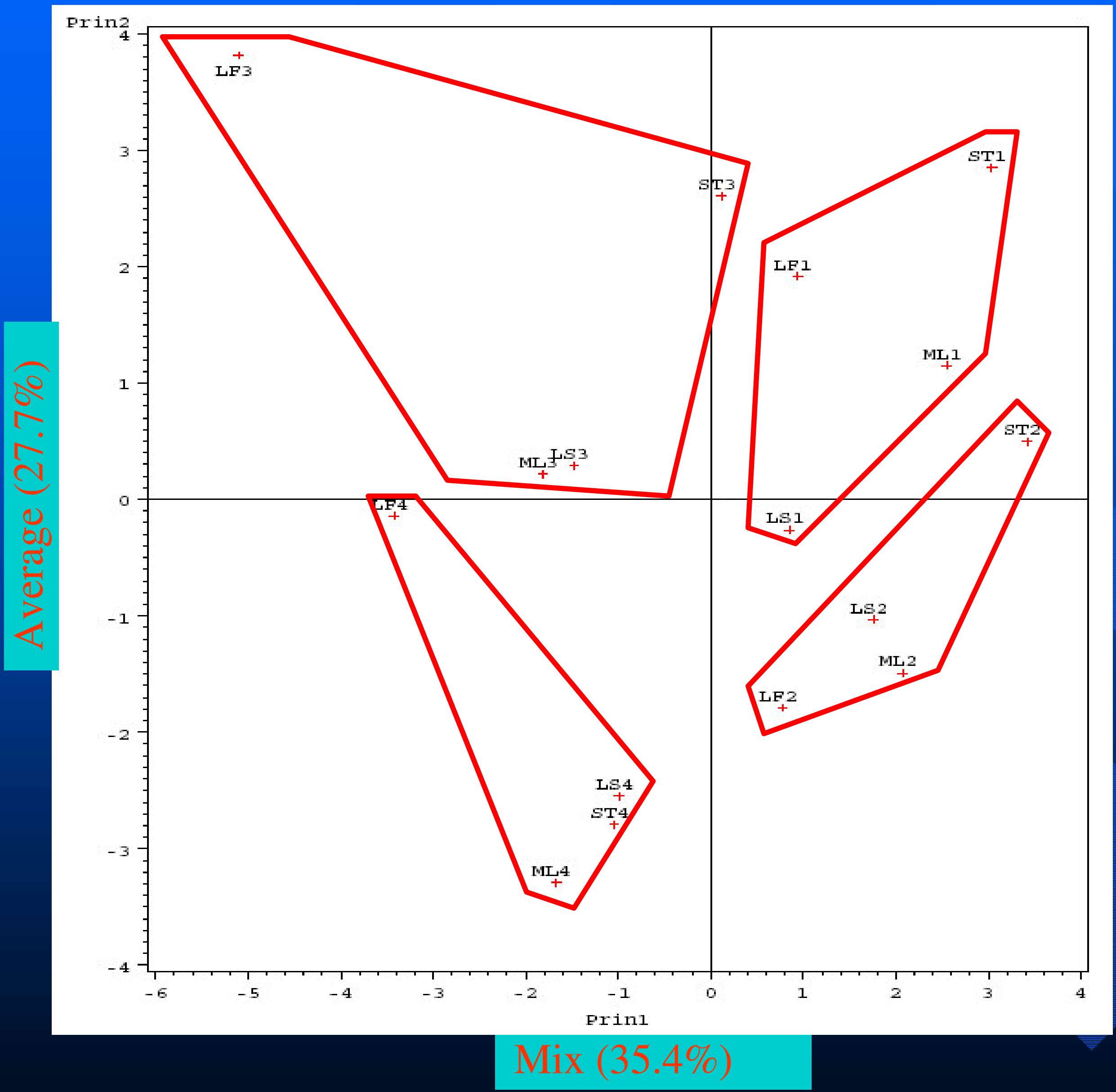


Eigenvector plot

(4 locations, 4 Seasons, All HAPs)

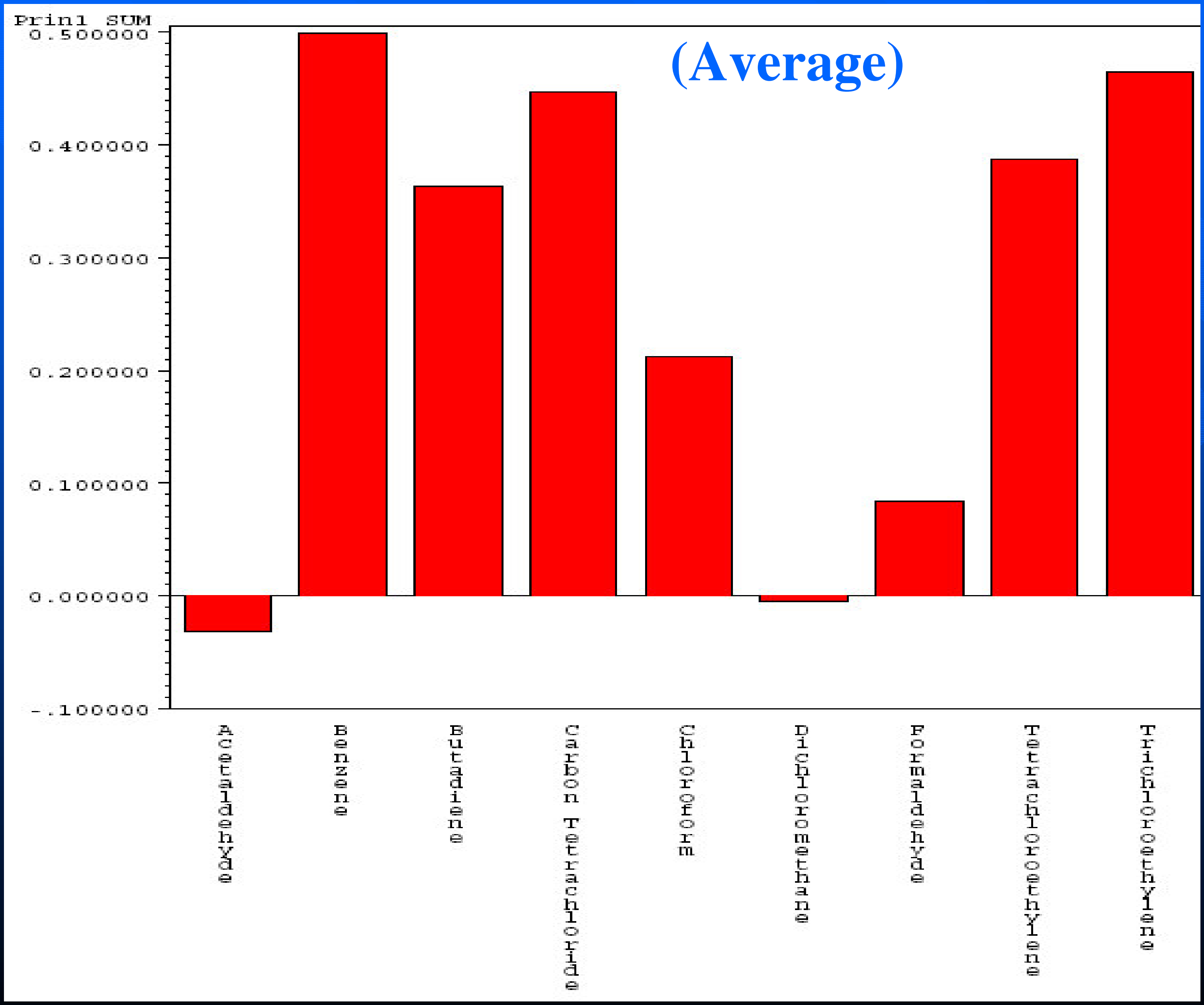


PCA (4 locations, 4 Seasons, All HAPs)

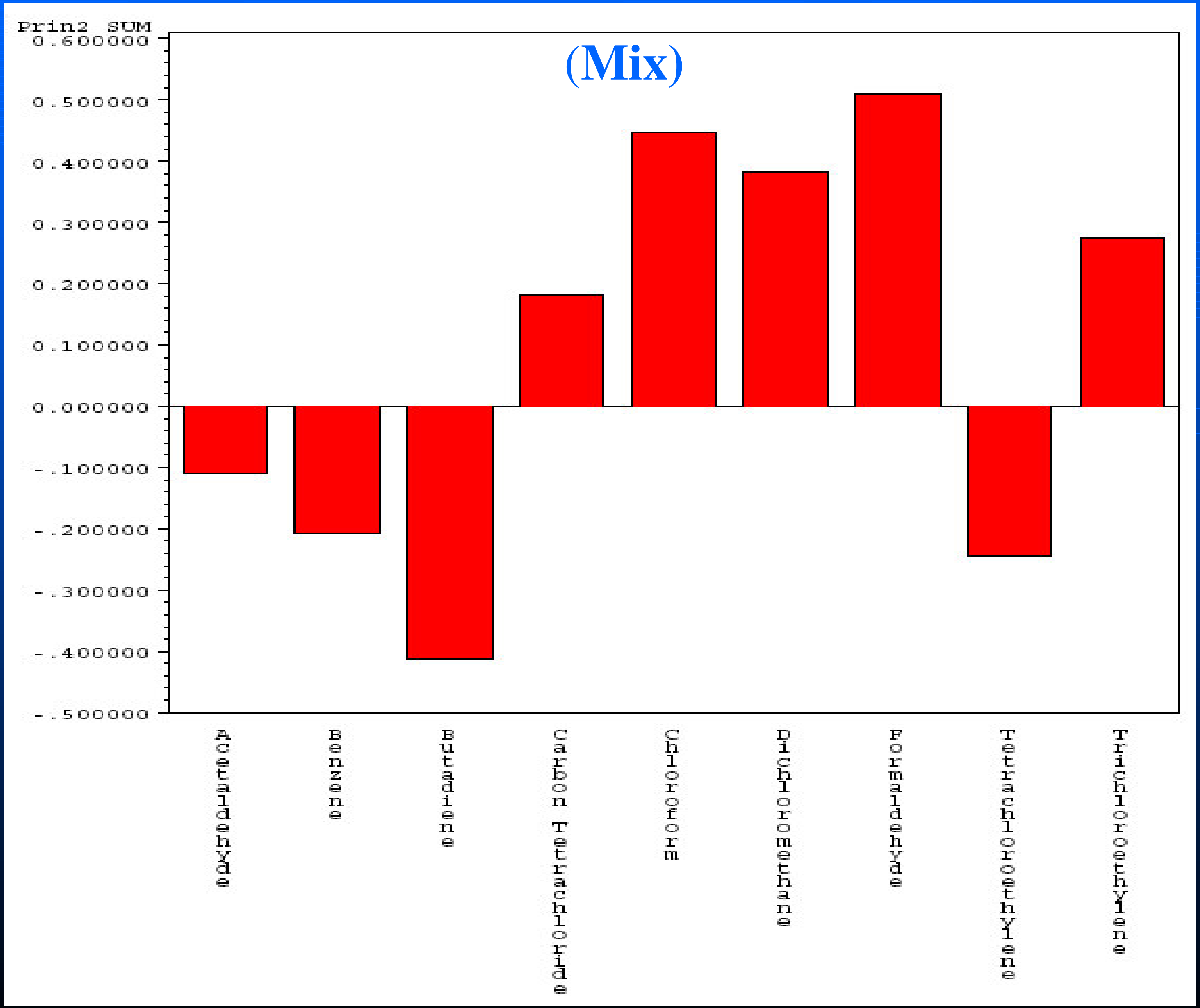


- Principal components
  - PC1: mix (of sources)
  - PC2: average (concentrations)
- Season effect
  - Seasons 1& 2 (spring and summer) are comparable for PC1 and PC2
  - Seasons 3 & 4 are different for PC2
- Lake Forest Park
  - LF3 has High Average (PC2) and a unique Mix (PC1)
    - » Wood smoke ? (see previous slide)
  - Excluding all LF, **ST** has high Average (PC2) within each season (except season 4 - winter)

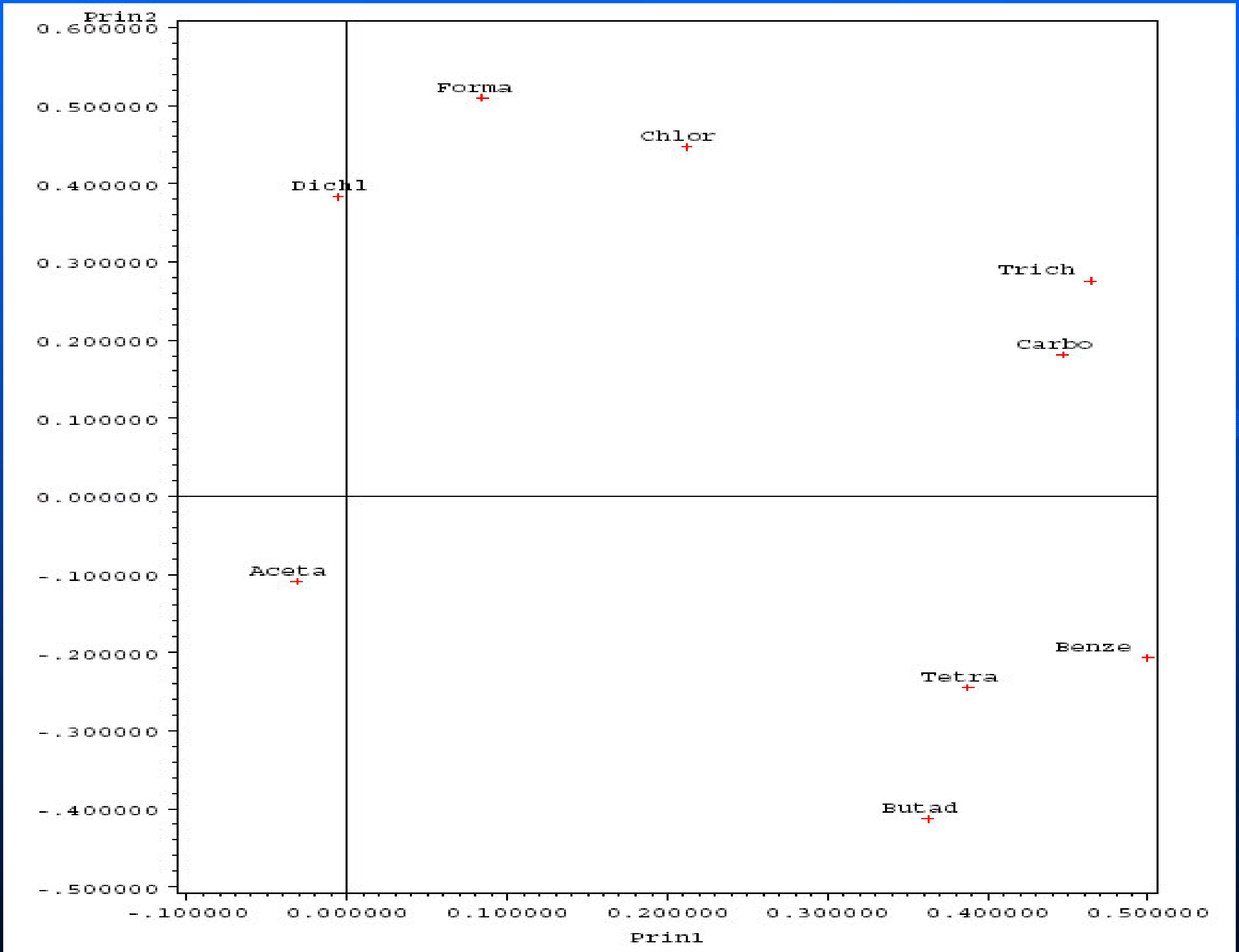
Eigenvectors for PC1
(6 Locations, 4 seasons, VOCs only)



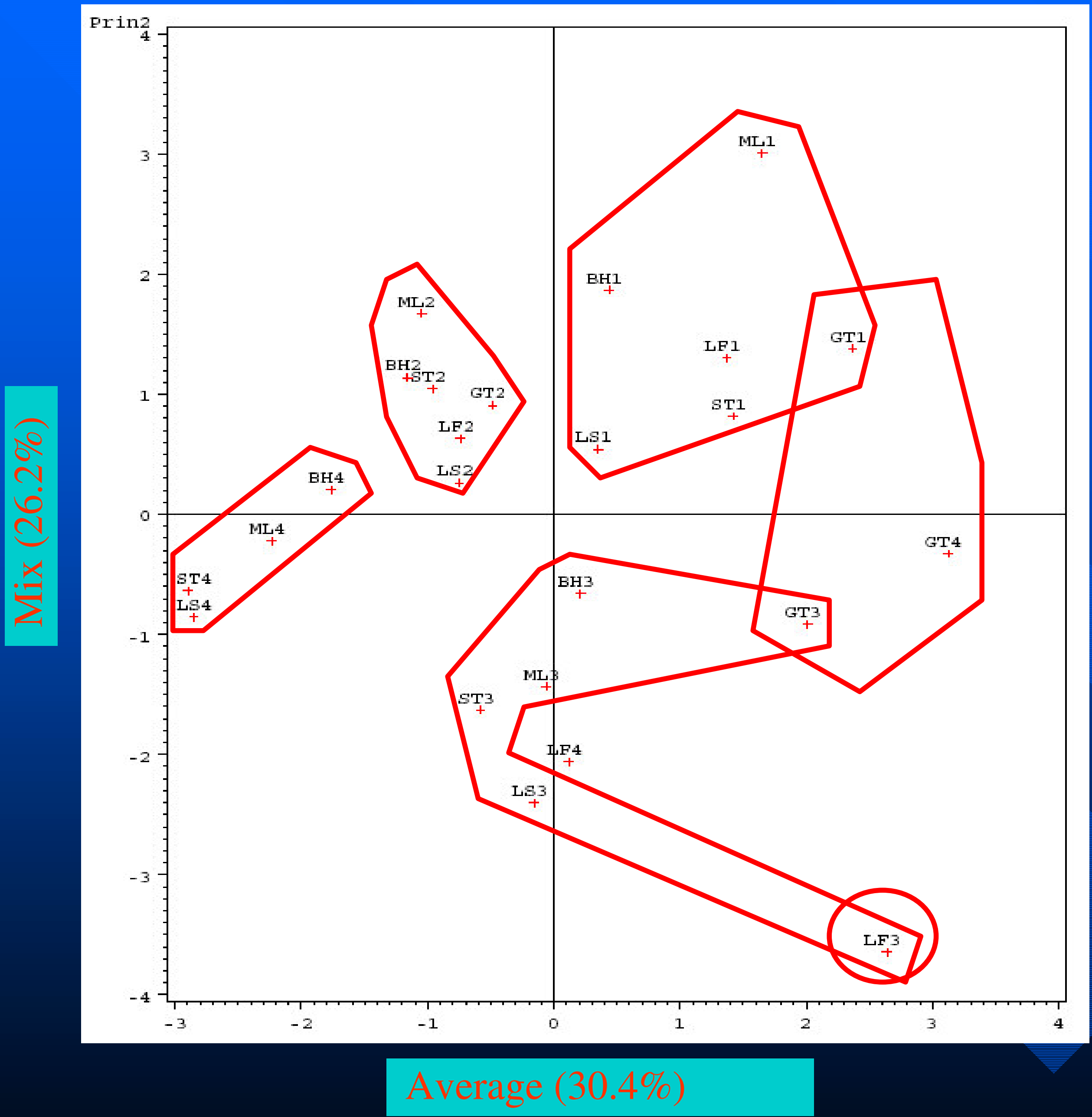
Eigenvectors for PC2
6 locations, 4 seasons, VOCs only



Eigenvector plot
6 locations, VOCs only



PCA (6 locations/VOCs only)



- Principal components
  - PC1: average (conc.)
  - PC2: mix (of sources)
- Season effect
  - Seasons 3&4 (fall and winter) are comparable for PC1 and PC2
- Lake Forest Park
  - LF3 has high average and unique mix
  - Excluding LF, GT(1,3,4) has high average

Ambient Concentrations: Conclusions

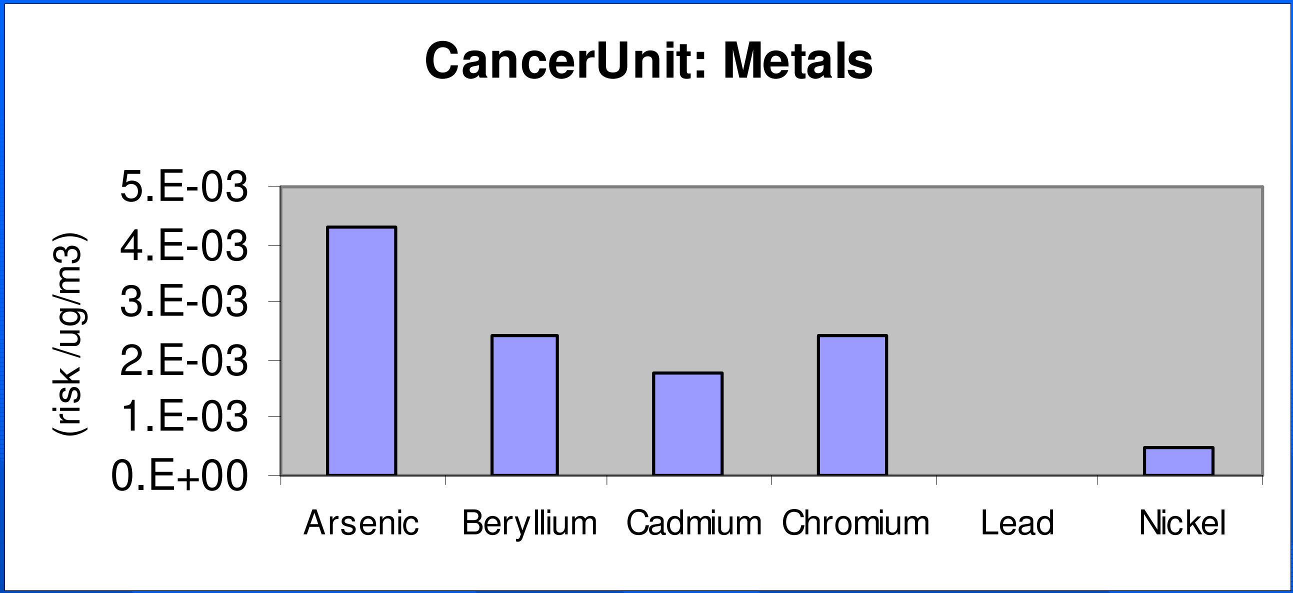
- HAPs exhibits temporal and spatial variability in the Seattle area
  - Greater seasonal variation than spatial variation
  - Most HAPs show significant spatial variation, with the exception of manganese, acetaldehyde, butadiene, and carbon tetrachloride
  - Lake Forest Park (LF) in Fall is significantly different from other sites (it's arsenic rich)
  - In the "4 locations/all HAPs" analysis: ST has higher average HAPs values than LS and ML, after excluding LF.
  - In the "all locations/ VOCs only" analysis: GT has the highest VOCs among all sites in all seasons, except for fall when LF prevails.

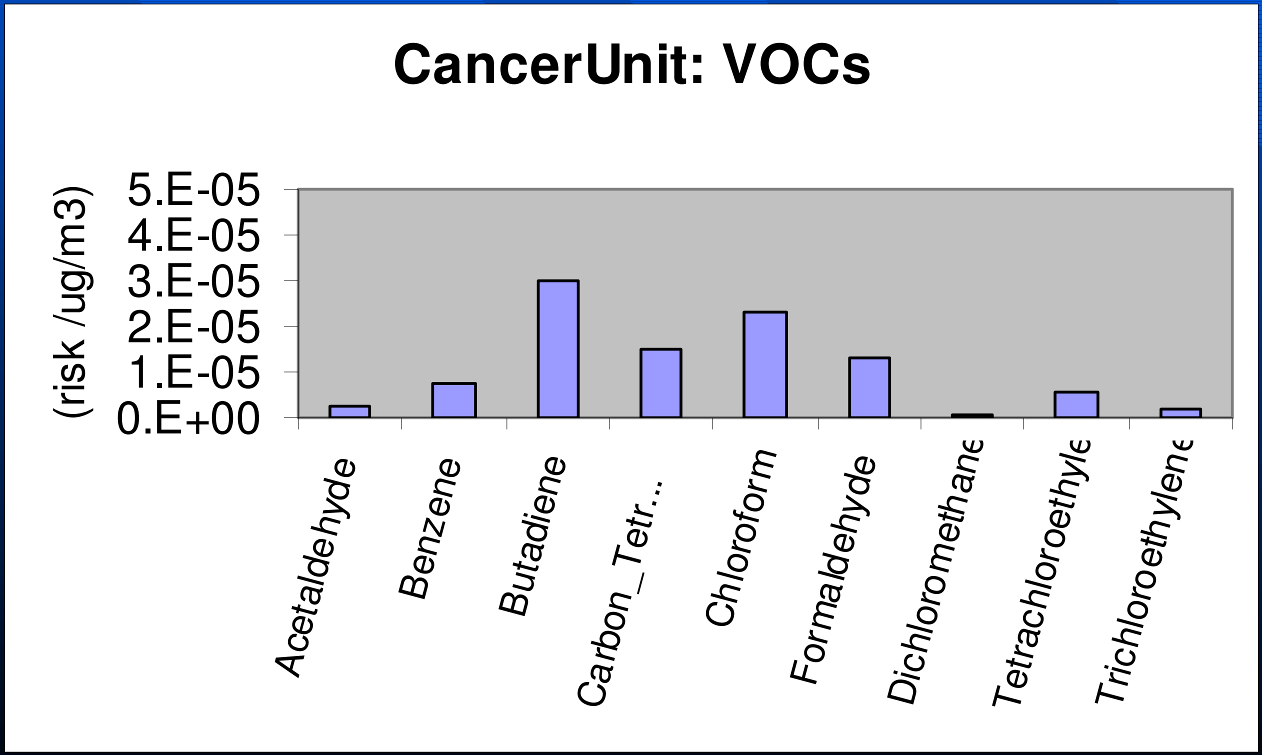
Risk Assessment

Cancer Risk Assessment

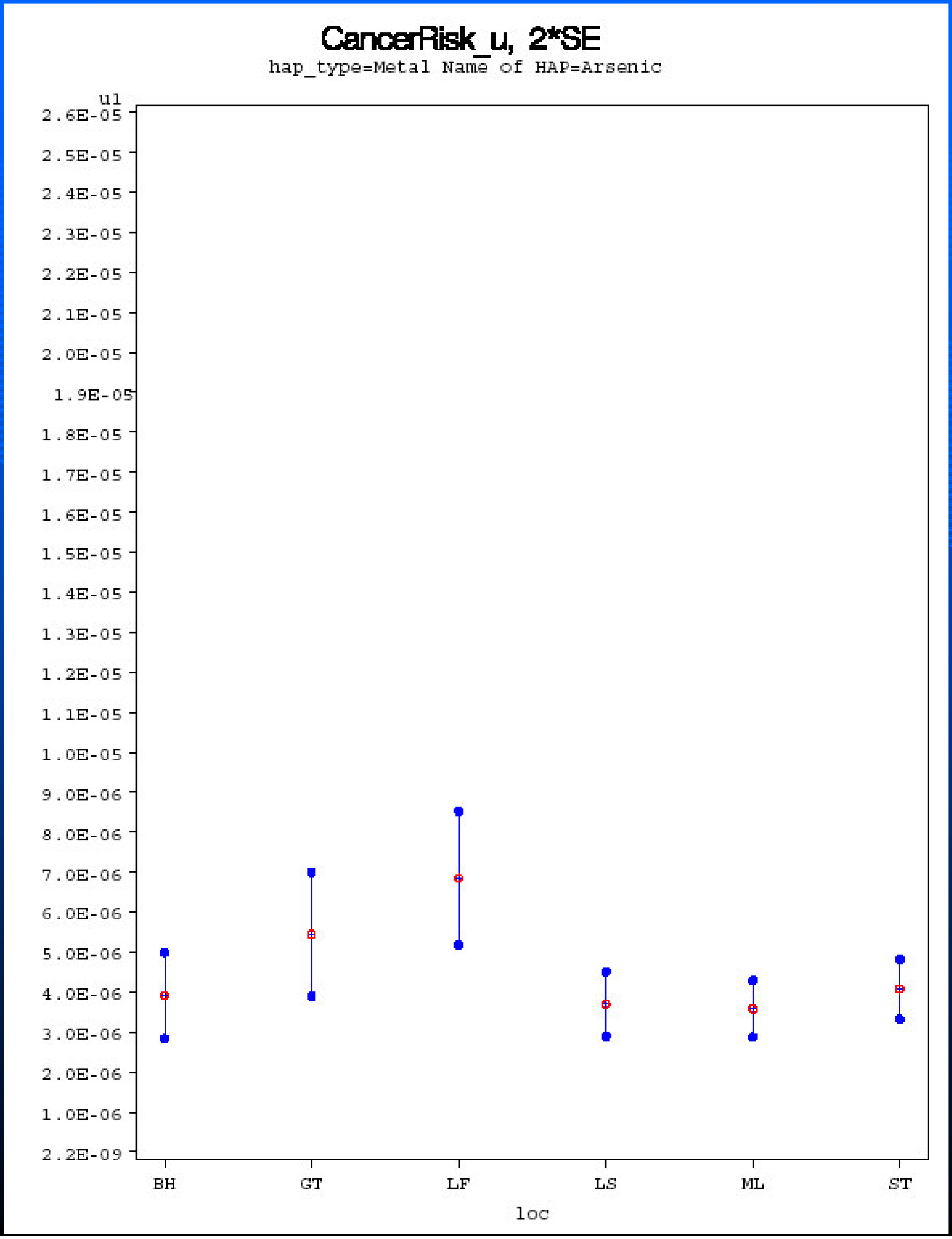
- Cancer Risk = Exposure * Toxicity
  - Exposure: annual average ($\mu g/m^3$)
  - Toxicity: unit risk (per $\mu g/m^3$)
    - » IRIS
    - » NATA
    - » CalEPA

Unit Risk

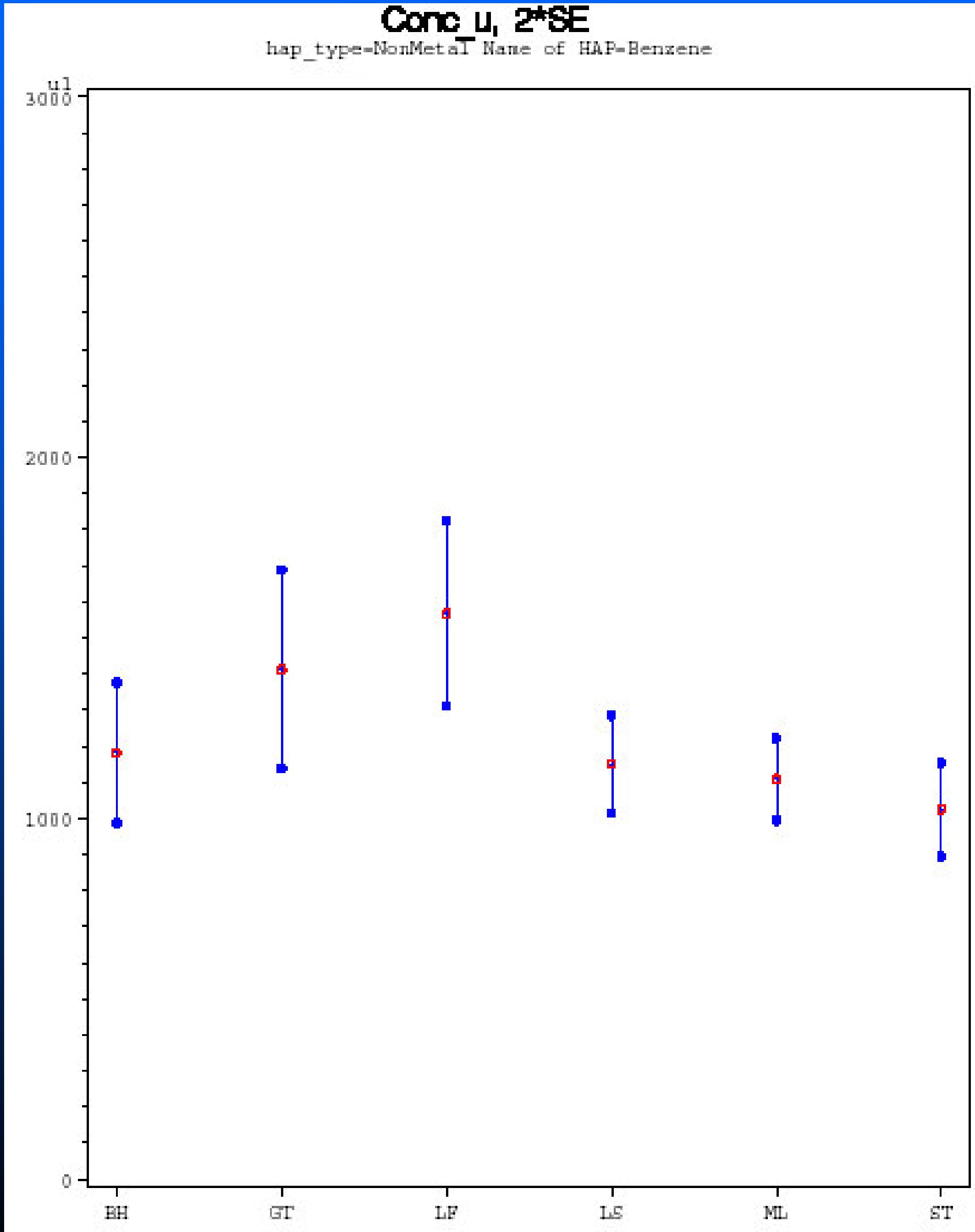

CancerUnit: Metals
(risk /ug/m3)
5.E-03
4.E-03
3.E-03
2.E-03
1.E-03
0.E+00
Arsenic
Beryllium
Cadmium
Chromium
Lead
Nickel

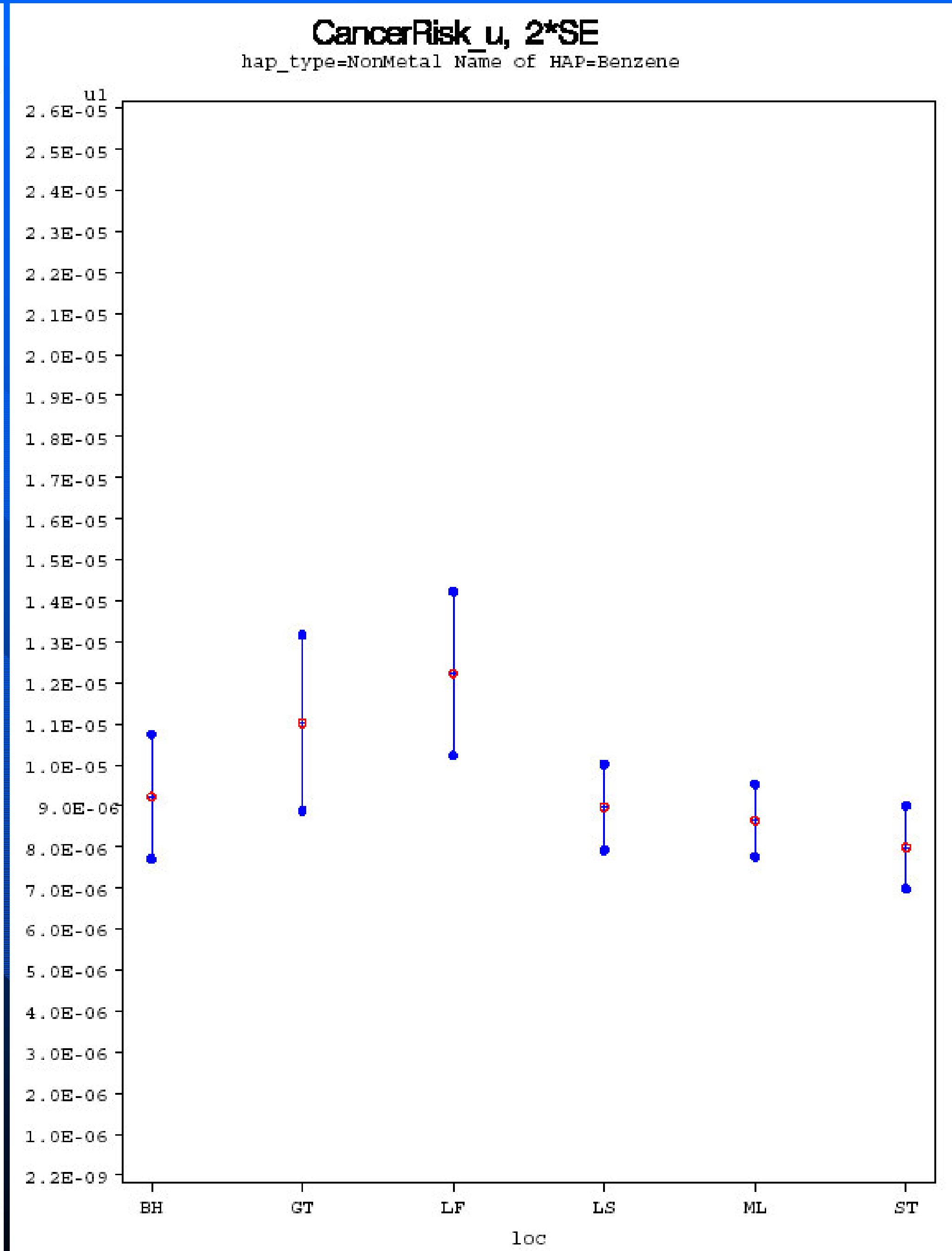

CancerUnit: VOCs
(risk /ug/m3)
5.E-05
4.E-05
3.E-05
2.E-05
1.E-05
0.E+00
Acetaldehyde
Benzene
Butadiene
Carbon_Tetr...
Chloroform
Formaldehyde

Cancer Risk: Arsenic



Cancer Risk: Benzene

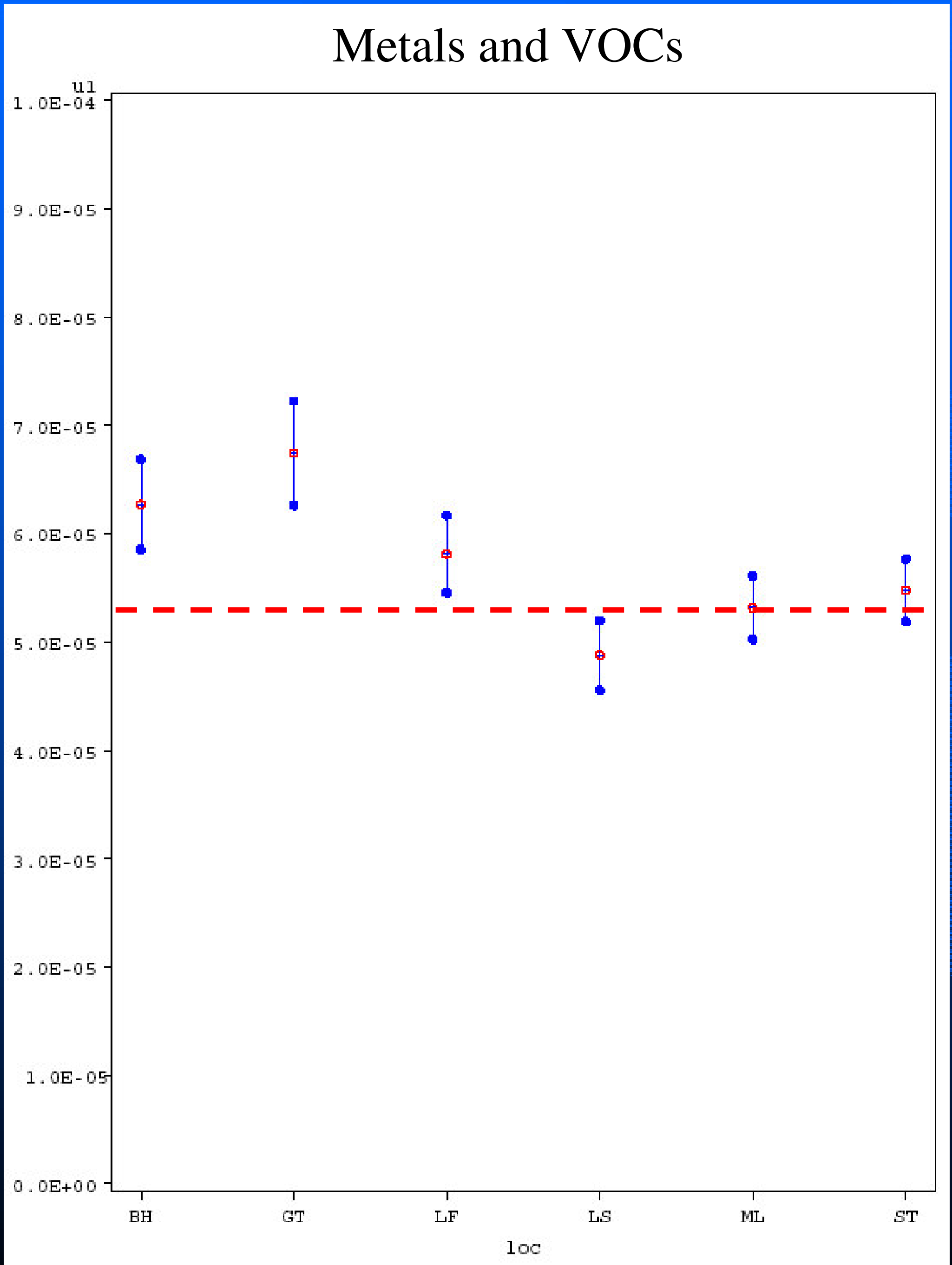


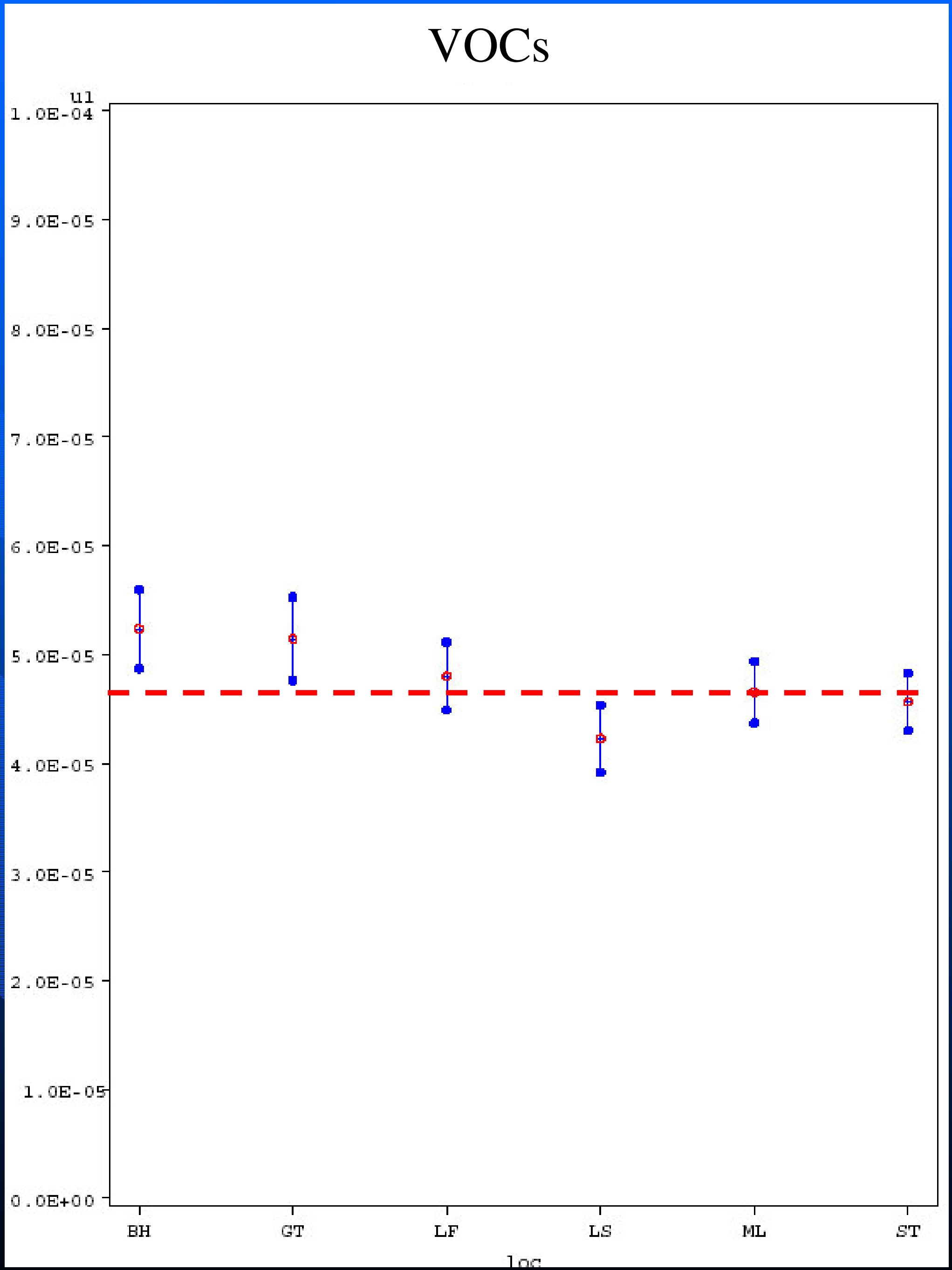


Cancer Risk - Continued

- The conclusions from the ANOVA model for ambient concentrations are applicable to the cancer risks
  - Because cancer risk is a linear function of Concentrations
- Interested in the "SUM" of cancer risks from measured HAPs at individual sites

Sum of Cancer Risk by Site



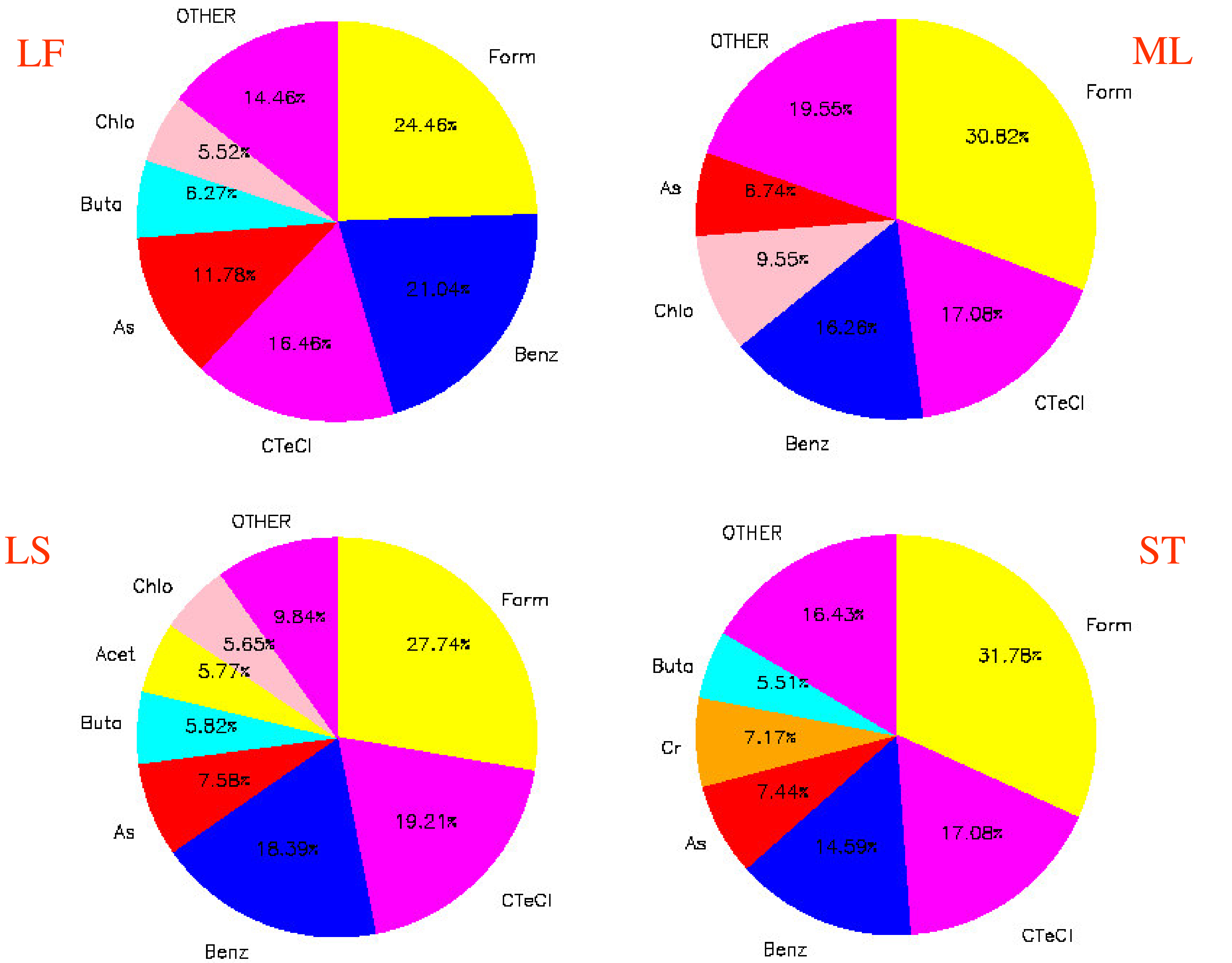


(Metals at BH & GT were analyzed on PM2.5 w/ XRF)

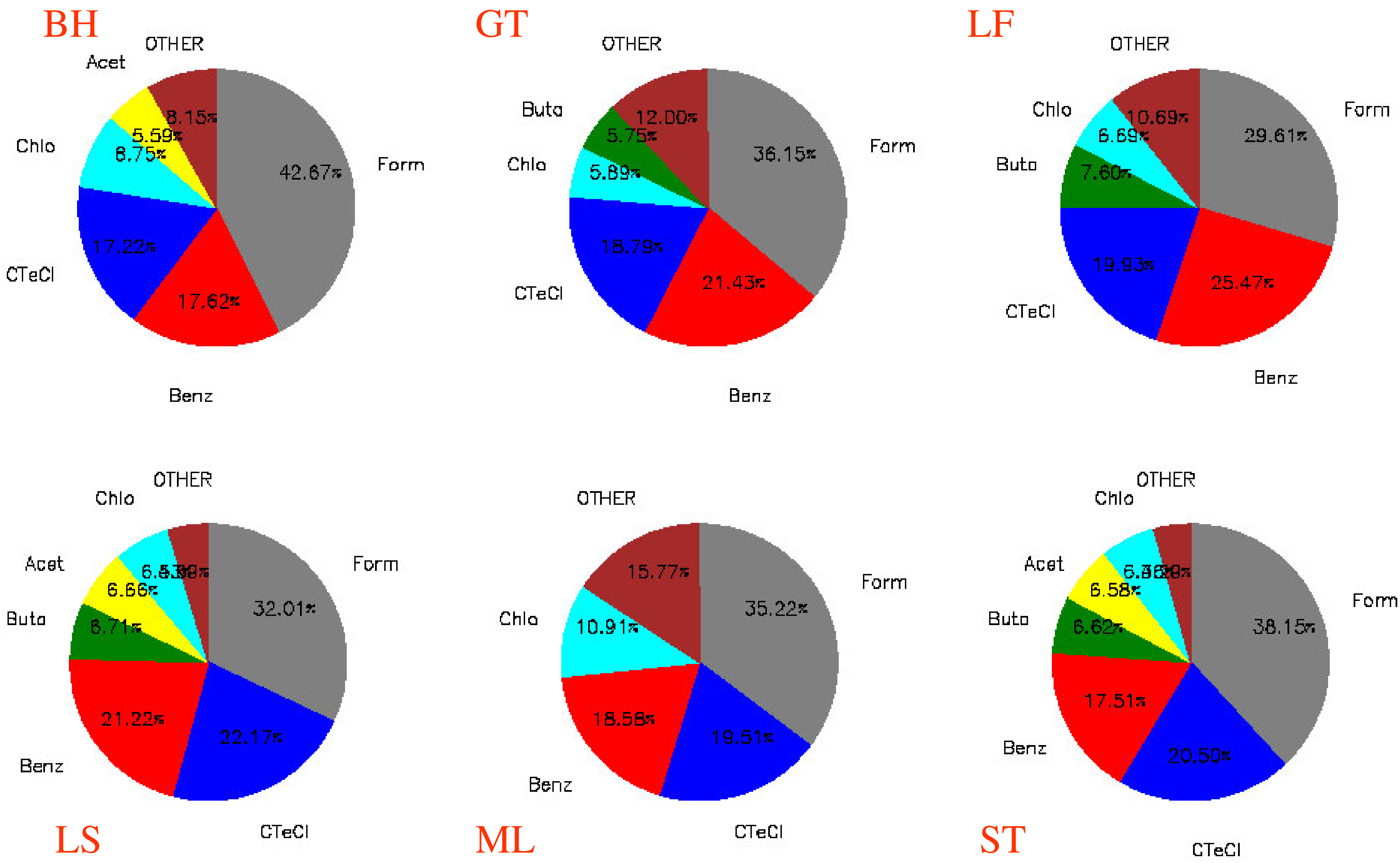
Abbreviation in Pie Chart

As	Arsenic
Be	Beryllium
Cd	Cadmium
Cr	Chromium
Pb	Lead
Mn	Manganese
Ni	Nickel
Acet	Acetaldehyde
Benz	Benzene
Buta	Butadiene
CTeCl	Carbon_Tetrachloride
Chlo	Chloroform
DCM	Dichloromethane
Form	Formaldehyde
TeCE	Tetrachloroethylene
TCE	Trichloroethylene

Contribution of cancer risks from VOCs and Metals



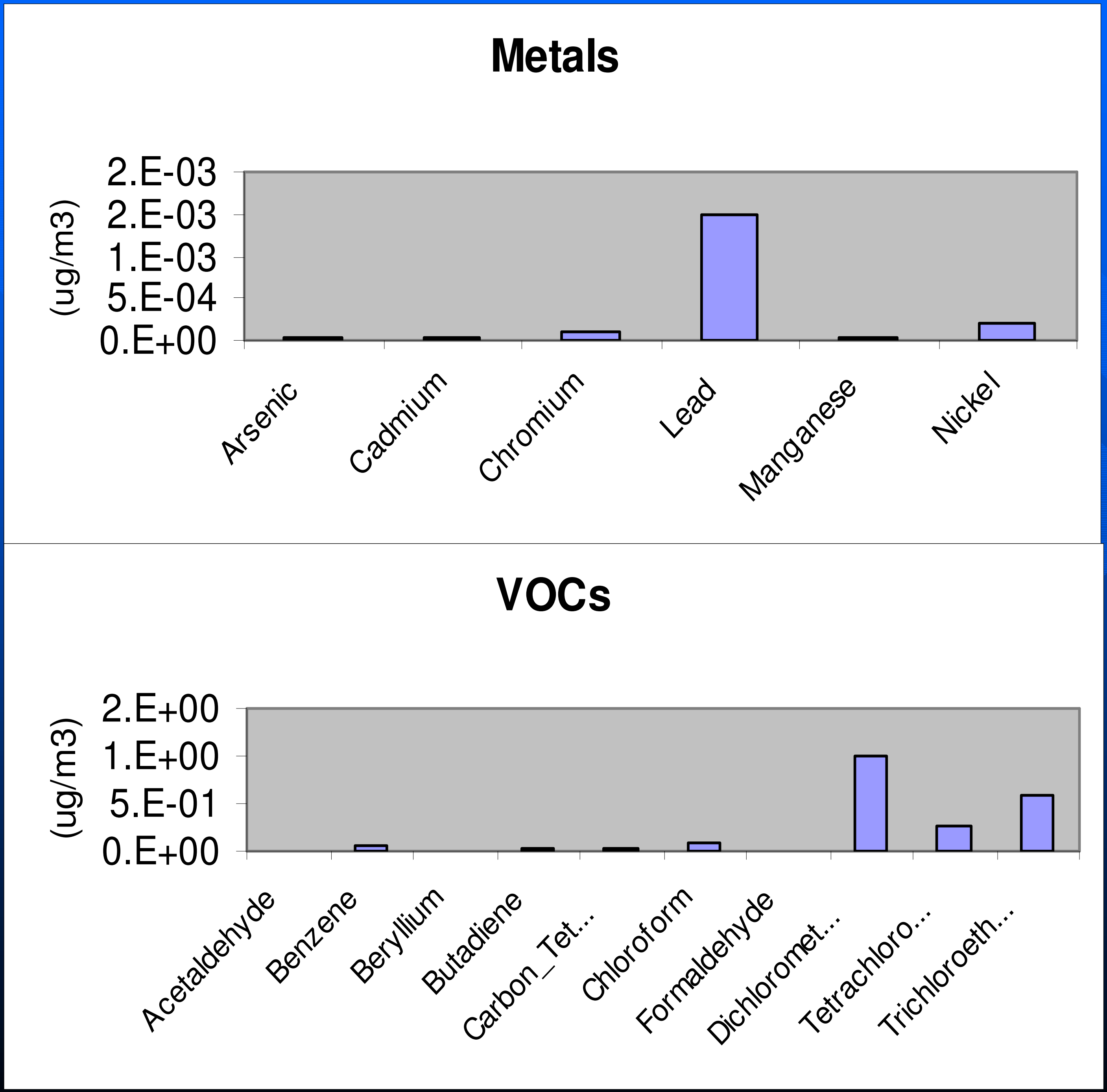
Contribution of cancer risks for VOCs only



Non-Cancer Risk Assessment

- Hazard Index = Exposure / Toxicity
  - Exposure: annual average ($\mu g/m^3$)
  - Toxicity, or reference concentration ($\mu g/m^3$)
    - » IRIS
    - » NATA
    - » CalEPA

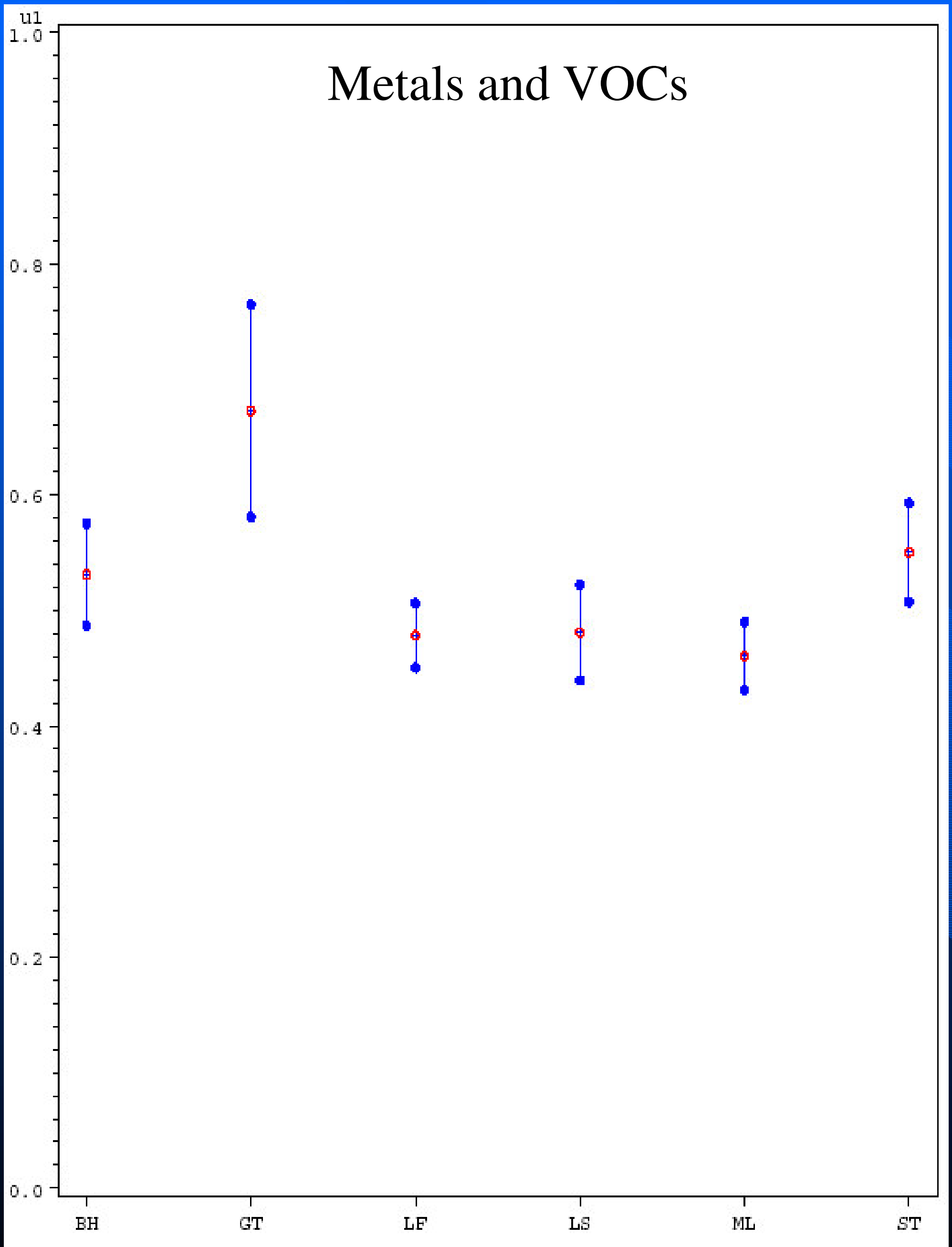
Reference Concentration (Toxicity)

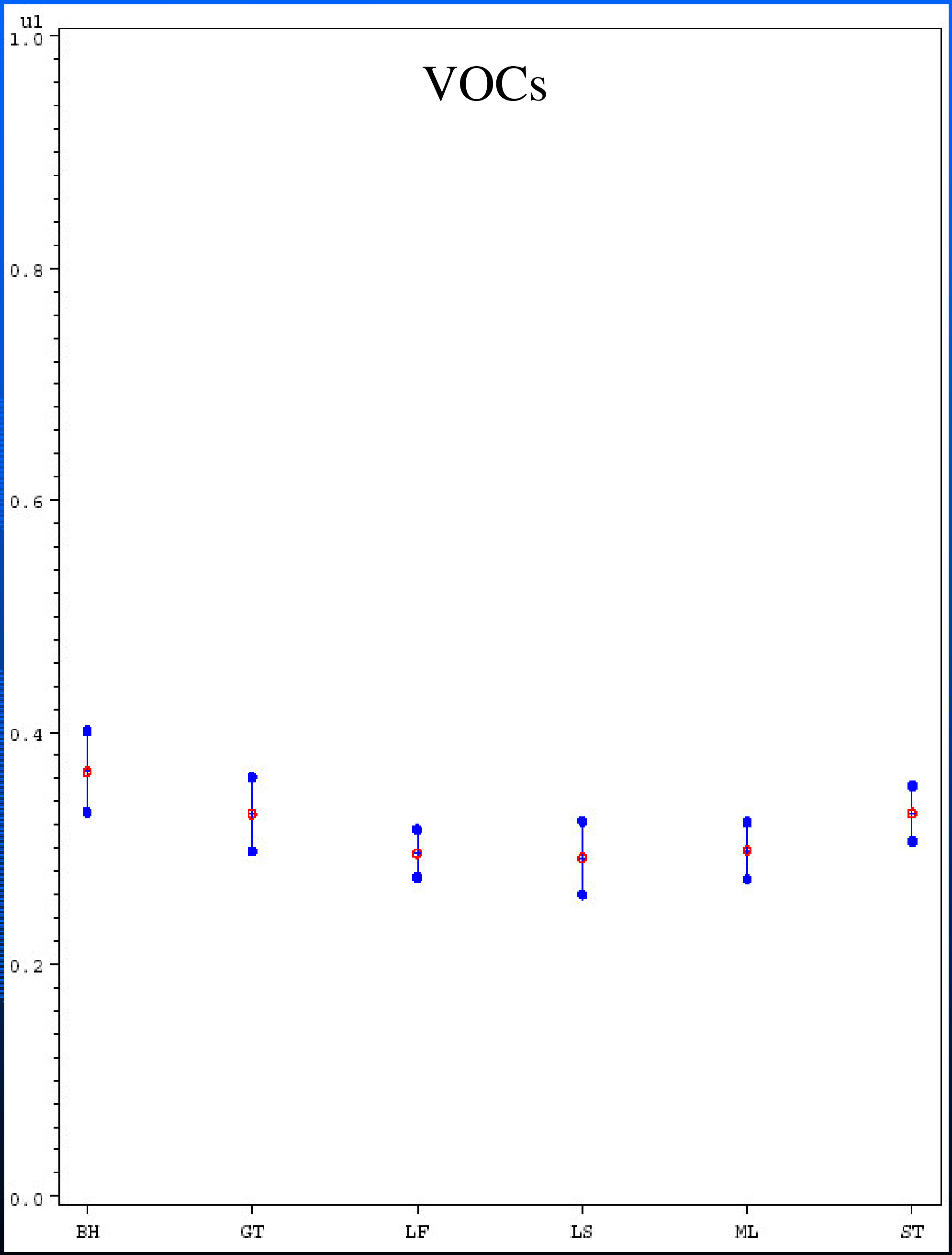


Hazard Index - continued

- The conclusions from the ANOVA model for ambient concentrations are applicable to the hazard indices
  - Because Hazard Index is a linear function of Concentrations
- Interested in the “SUM” of hazard indices from measured HAPs at individual sites

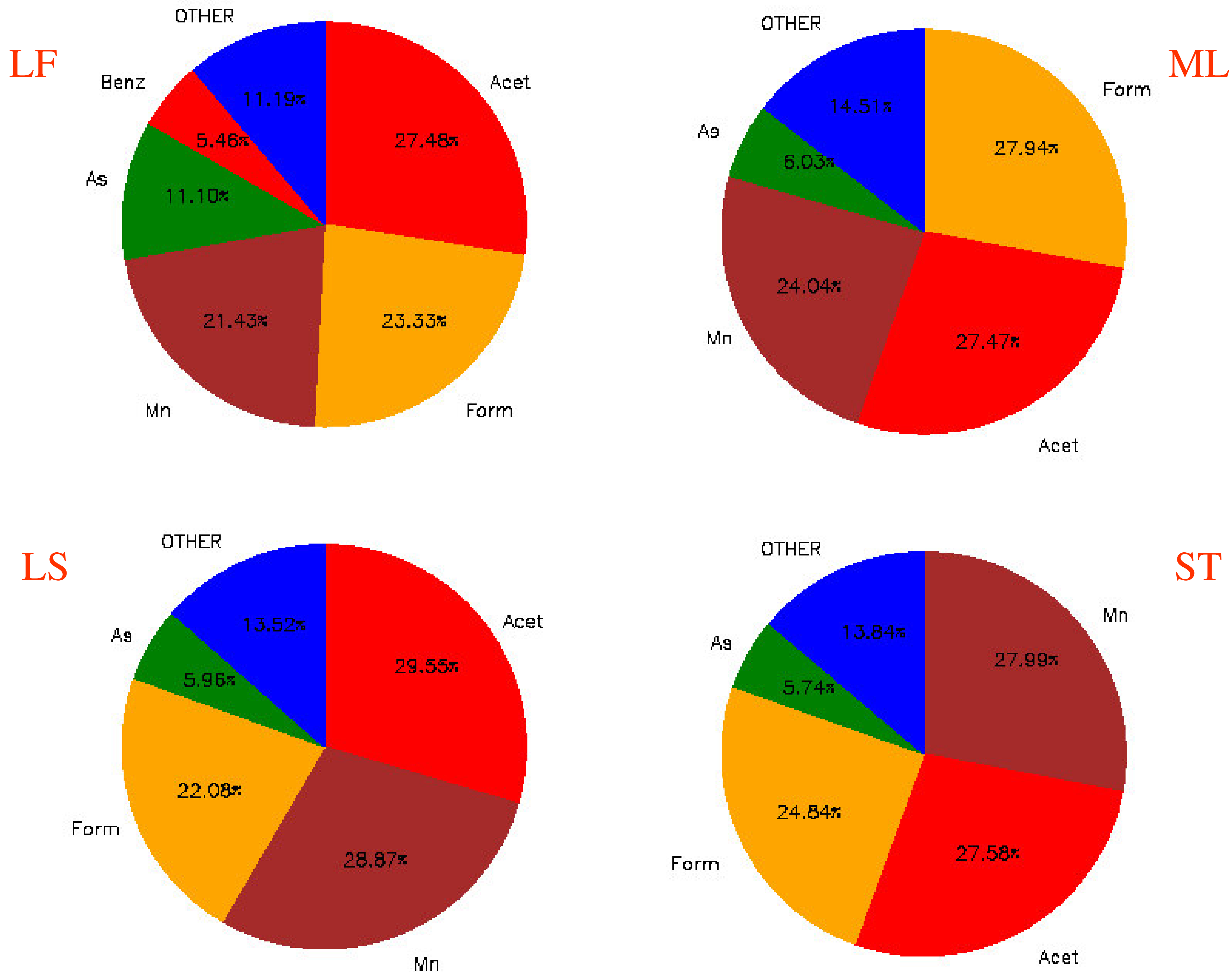
Hazard Index (SUM)



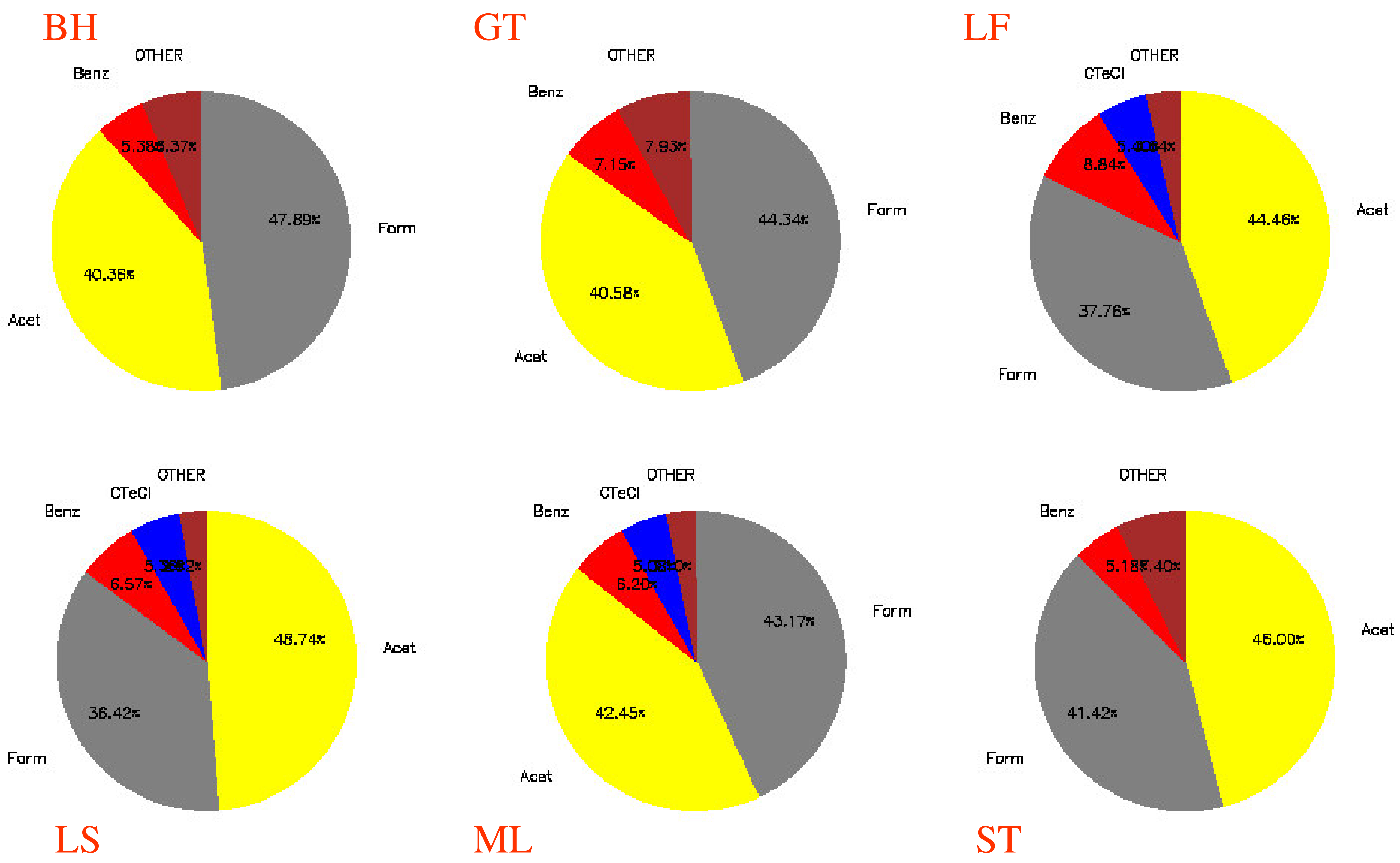


(Metals at BH & GT were analyzed on PM2.5 w/ XRF)

Contribution of non-cancer risks from VOCs and Metals



Contribution of non-cancer risks for VOCs only



Conclusions

- Sum of cancer risks is higher than $1x10^{-6}$ for all sites
  - Beacon Hill and Georgetown may be higher than others
  - Highest contributions from Formaldehyde, Benzene, Carbon tetrachloride
- Sum of non-cancer risks is <1 for all sites
  - GT may be higher than LS, ML, and LF
  - Highest contributions from Formaldehyde, Acetaldehyde, Benzene, Manganese

Limitations

- Spatial and temporal variation analysis
  - Compatibility issues of metal data from $PM_{2.5}$ and TSP
  - Limited number of sites (6→4) and monitoring duration. Due to the incompatability issues for metals measurements, GT and BH had to be removed from metal analysis.
  - Location of sites
- Risk Assessment
  - Still need to determine uncertainties from measurement errors, spatial and temporal variations, and cancer potencies/toxicity
  - Not population based (yet)